

IMPLEMENTATION OF VEHICLE STOPPING LOGIC IN THE INDO-SWEDISH ROAD TRAFFIC SIMULATION MODEL

by

N. N. PRASAD



DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
MAY, 1985

CE
1985
M
PRA
IMP

IMPLEMENTATION OF VEHICLE STOPPING LOGIC IN THE INDO-SWEDISH ROAD TRAFFIC SIMULATION MODEL

**A Thesis Submitted
In Partial Fulfilment of the Requirements
for the Degree of
MASTER OF TECHNOLOGY**

**by
N. N. PRASAD**

**to the
DEPARTMENT OF CIVIL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY KANPUR
MAY, 1985**

SREE GURU RAGHAVENDRAYA NAMAHA

DEDICATED
TO
MY BELOVED PARENTS

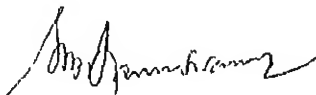
CE-1905-M-PRA-IMP

9-8 86

LIBRARY
91891
No. 1

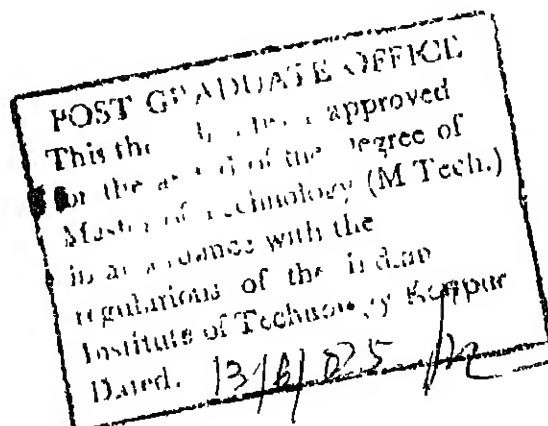
CERTIFICATE

This is to certify that the thesis entitled
'Implementation of Vehicle Stopping Logic in the Indo-Swedish
Road Traffic Simulation Model' submitted by Mr.N.N. Prasad,
in partial fulfilment of the requirements for the degree of
Master of Technology of the Indian Institute of Technology,
Kanpur, is a record of bonafide work carried out by him under
my supervision and guidance. The work embodied in this thesis
has not been submitted else where for a degree.



May, 1985

(Dr. S.P. PALANISWAMY)
Assistant Professor
Department of Civil Engineering
Indian Institute of Technology, Kanpur



ACKNOWLEDGEMENTS

It is with pleasure that I express my gratitude to Dr. S.P. Palaniswamy for his valuable guidance, constant encouragement and cooperation in successful completion of this work.

I am highly grateful to my parents, brother Manju and sisters Leela and Anu for the affection, help and encouragement showered on me.

I am thankful to my classmates Chalapathi, Thomas Vergees, Vijay Agrawal, Shrikanth for their help in one way or the other during my stay at IIT Kanpur.

I am highly thankful to my friends Mr. P.G.Yogmdra and B.G. Acharya and Radhakrishna for their help during my thesis work. I am also thankful to all my friends who made my stay at Kanpur a memorable one.

I am grateful to all teachers who taught me at IIT Kanpur.

My thanks are due to Mr. G.S. Trivedi for his excellent typing and Mr. R.S. Dwivedi for neat cyclostyling.

N.N. PRASAD

CONTENTS

	PAGE
LIST OF TABLES	v
LIST OF FIGURES	vi
ABSTRACT	vii
CHAPTER I : INTRODUCTION	1
1.1 Highway Traffic Models	1
1.2 A Review of Literature	1
1.2.1 Analytic models	1
1.2.2 Simulation models	6
CHAPTER II: COMPUTER SIMULATION APPROACH	15
2.1 Why Simulate?	15
2.2 What is Simulation?	16
2.3 Simulation Languages	20
2.4 SIMULA	21
2.5 Comparison of Simulation Languages	22
CHAPTER III: MODELLING OF VEHICLE STOPPING AND STARTING FLOW SEQUENCE IN THE 'ISRTSM' AND ITS APPLICATIONS	24
3.1 Model Development	24
3.2 Selection of Traffic Model from a Set of Models	24
3.3 Description of Indo-Swedish Road Traffic Simulation Model (ISRTSM)	25
3.3.1 Power/weight ratios	28
3.3.2 Basic desired speeds	29
3.3.3 Position within platoon and time headways	37
3.3.4 Time headway distribution for constrained vehicles (log-normal)	42
3.3.5 Time headway distribution for constrained vehicles (exponential)	42
3.3.6 Platoon size distributions	43
3.3.7 Probabilities of gap acceptance	44
3.4 Development of Stopping Algorithm and Queue Submodel	46
3.5 Application of the Model	54
3.5.1 Simulation of signalized intersection	54
3.5.2 Establishing volume warrants	55
3.5.3 Simulation of density scanners	56

	PAGE
3.5.4 Simulation of system of signalized intersections and unsignalised intersections	57
3.5.5 Accident model and accident analysis	57
CHAPTER IV : INPUT AND OUTPUT OF THE MODEL	59
4.1 The Input of the Model	59
4.2 The Output of the Model	61
CHAPTER V: RESULT DESCRIPTION AND CONCLUSIONS	64
5.1 Result Description	64
5.2 Conclusions and Scope for Future Work	66
REFERENCES	69
APPENDIX-A DESCRIPTION OF IMPORTANT PROCEDURES AND VARIABLES IN ISRTSM	73
APPENDIX-B FLOW CHART OF PRESENT WORK	87
APPENDIX-C LIST OF PROCEDURE ADDED, PROCEDURES CHANGED IN ISRTSM	93
APPENDIX-D EVENT FILE DETAILS	97

LIST OF TABLES

TABLE NO.	TITLE	PAGE
1.1	Greenshield's Starting Delays for Discharging Vehicles from Queue Head	10
1.2	Starting Delays for Four Wheelers in India	11
1.3	Starting Delays for Two Wheelers in India	12
3.1	P-value Distributions for Each Vehicle Type (For Swedish Conditions)	30
3.1a	P-distribution Function for Various Vehicle Classes (For Indian Conditions)	32
3.2	Basic Desired Speed Distribution-Fast Moving Vehicles(For Indian Conditions)	38
3.2a	The V_o Distribution Function (For Swedish Conditions)	40
3.3	Dimensions of Vehicles	47
4.1	Schematic Description of Output Data	62

LIST OF FITURES

FIGURE NO.	TITLE	PAGE
1.1	Relation Between Traffic Volume N and Density D	3
2.1	Flow Chart for Simulation	17
2.2	Simula Pyramid	21
3.1	The Position of the Simulation Program in the Program System	26
3.2	P-Distributions for Each Vehicle Class (Swedish Conditions)	33
3.2a	P-Distribution for Cars (Indian Conditions)	34
3.2b	P-Distribution for Buses (Indian Conditions)	35
3.2c	P-Distribution for Trucks (Indian Conditions)	36
3.3	Basic Desired Speed Distribution (Indian Conditions)	39
3.3a	V_0 Distributions (Swedish Conditions)	41
3.4	Stretch of Simulated Road	49

ABSTRACT

The traffic engineers have used the tool of modelling to understand and analyse the complex phenomenon of traffic. Analytical and simulation models have been used quite extensively for the above purpose. These models have aided in establishing warrants for transportation facility improvements.

In the above models all aspects of movement of vehicles excepting, stoppages of vehicles on road especially prevalent on Indian highways have been considered. The vehicular stoppages near narrow bridges, near road repairing spots and near signalized intersections and near random bus stops in rural highways are some of the examples which require development of adequate modelling to study the complete traffic movement behaviour.

In this study an attempt has been made to incorporate the vehicular stoppages near signals in the 'Indo-Swedish Road Traffic Simulation Model' developed at I.I.T. Kanpur in collaboration with Swedish National Road and Traffic Research Institute. The effect of such stoppages on the other vehicles is queue formulation is also modelled. In 'Indo-Swedish Road Traffic Simulation Model' the vehicles are moved depending on road interaction and vehicular interactions and behaviour of drivers. In this thesis the interaction of vehicles with signals when they encounter it is incorporated. The applications of this modelling approach to vehicular stoppages are explored and suggestions to implement the applications are briefly given.

CHAPTER I

INTRODUCTION

1.1 HIGHWAY TRAFFIC MODELS

The traffic flow process on streets and highways is a complex phenomenon. The behaviour of vehicles along a road is either described by a set of mathematical equations or by heuristic methods, in which there are facilities to represent the stochastic decision of each driver. Such representation is called highway traffic model.

Traffic flow modelling enables better understanding of the phenomenon of vehicular movements. These models should be helpful for engineers in establishing standards for road improvements which ensures safety, easy operations of vehicles on roads and economy.

The traffic models are of two types. A set of mathematical equations, used for solution of traffic problems are called Analytical models. The other approach is to model the traffic flow logic on a computer which not only includes a set of equations governing the vehicle movement but also stochastic decisions of drivers which are known as simulation models.

1.2 A REVIEW OF LITERATURE

1.2.1 Analytical Models

Empirical work on lengths of road is associated largely with Wardrop [30] and Norman [19]. These studies are

particularly concerned with the relation of traffic speed to the volume of traffic and to the width of road. In some respects these relations are fairly precisely known, but in others, such as the effects of traffic composition and of varying proportion of oncoming traffic they are less understood. Estimates are also available for the effect of such factors as parked vehicles, pedestrians and grades. Following on from the empirical determination of the relation between mean traffic speed and flow or density is the theory mainly associated with Lighthill and Whitham [13]. Traffic is regarded as a fluid and certain results about the propagations of 'waves' and 'shock waves' have been obtained. Lighthill and Whitham [13] used the mechanics of compressible fluids to explain the flow of traffic on long crowded roads on a single lane. A functional relationship between flow and concentration for traffic was postulated, and from this a theory of the propagation of changes in traffic distribution is deduced. They called the relationship between flow and concentration as the fundamental diagram of road traffic as shown in Fig. 1.1. This work of Lighthill and Whitham [13] is the first paper to appear in the literature using the methods of fluid dynamics to explain phenomena that had previously been observed in road traffic.

The above relationship holds good as long as a two lane road experiences very high volumes in both the directions. It has not yet been studied as to how this

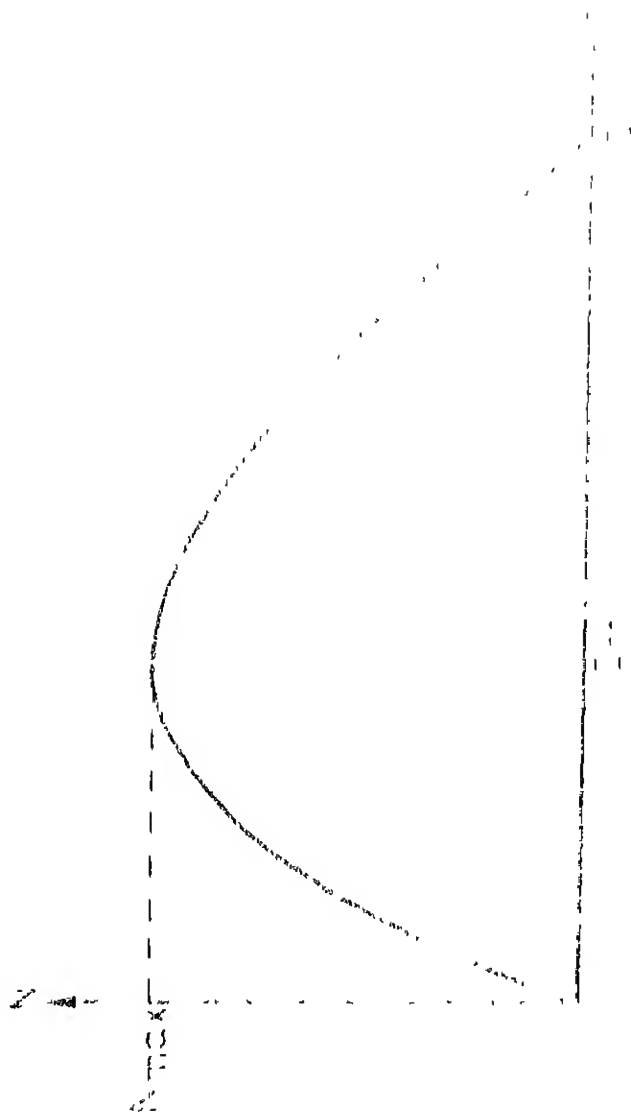


Fig 1-1-1
 (2-5-1)

relationship will be affected when frequent overtakings are prevalent under low to medium flow conditions. It seems the complex nature of road traffic violates the continuity assumption required in the model. Also, this theory does not take account of the properties of individual vehicles and therefore it cannot be expected to explain traffic behaviour in any detail.

which

Of other theories/deduce the properties of a traffic stream from the behaviour of the individual vehicles of which it is composed are those due to Schuhl [25] and Kometani[12]. Quoting from Haight [9], who gives a brief general survey of the literature on traffic theory 'Schuhl for examples, considers a two lane road in which the sole constraint to free speed (the distribution of which he assumes to be known) is the passing maneuver. For most of his work, Schuhl[25] confines himself to averages-although he does allow negative exponential gaps in the oncoming traffic. In particular he assumes that cars in the same directions are overtaken at free speed and at equally spaced intervals.'

'The most detailed analysis of the geometry of the passing Maneuver of which I am aware is that of Kometani. Two and three lane highways are considered with different poisson streams in each lane. The distribution of free speeds assumed to be discrete, as are the units of time. Assuming values for several constants such as headway, time to pass etc., Kometani obtains a formula for the probability of n vehicles,

$n = 1, 2, \dots$, being passed at a time'.

The major criticism of the above two papers are that they suffer from the disadvantage that the mathematical analysis given is not exact in that various approximations and simplifying assumptions have to be made. Exact analysis of these models would be very difficult, so it is not easy to extend their results.

Tanner [28] presented a theoretical formula for the average speed achieved over a long journey by a vehicle. Except for the vehicle whose behaviour is studied, other vehicles in each direction are assumed to travel at the same speed, and are spaced at random, but with a certain minimum distance between vehicles. The vehicle being studied wishes to travel faster than other vehicles. When it overtakes it must pass the whole of a bunch of vehicles at minimum spacing in a single maneuver it overtakes without delay if there is a sufficient gap in the opposing traffic. If delay occurs then a greater gap in the opposing stream is required to allow for time lost in accelerating. An important feature of the results obtained by Tanner is that when the traffic flows, increase beyond a certain level, appreciably below the theoretical capacity of the road the fast vehicle cannot maintain a higher average speed than that of the other vehicles. The whole time is spent waiting for opportunities to overtake, and the average wait per overtaking becomes very large.

Miller[14] proposed that on roads vehicles which are uninterrupted by traffic signals, intersections, etc. vehicles should be considered as travelling in random queues by which he means that the intervals between the tail of one queue and the head of the next follow the exponential distribution. Criteria based on headways and relative velocities are developed to determine when a vehicle is said to be under queue condition. Miller's random queues model appears very much more realistic as a representation of road traffic witnessed on two lane highways. If the road has both straight and winding sections, or narrow and wide sections, then the overtakings will all occur on the same part of the road and just down stream from this wider or straighter section, the queues of vehicles will themselves occur in bunches.

Carter and Palaniswamy [4] and Palaniswamy[20] have proposed a markov model to describe the traffic flow fundamental diagram in terms of state variants. After verifying the traffic flow process as a Markov process the authors have attempted to use dynamic programming concepts along with Markovian model for the on line control of traffic flow in the Baltimore Harbour Tunnel. The formalism was found to be quite satisfactory for evaluating control policies to improve the traffic flow in capacity restricted facilities.

1.2.2 Simulation Models

In recent years, a number of traffic simulation models have been developed for two lane roads. These models describe

the behaviour of traffic stream by considering in detail the behaviour of individual vehicles as they move over the specified section of the road. They are briefly reviewed here.

Shumate and Dirkson [26] model uses a Poisson distribution for headways and a normal distribution of desired speeds. For overtaking manoeuvre, 'valour' factor, which gives the probability of driver accepting a risk, is used. The model uses SIMCAR Language.

Paul Warnshuis [21] developed a simulation model in which drivers are always assumed to accept an overtaking gap if it allows sufficient safety margin. The results of two different desired speed distributions show that the speed distribution is not critically important.

in U.S.A.

Janoff and Cassel [11] model developed/forms the basis for North Carolina State University model. This model was primarily concerned with evaluating the safety benefits of remedial passing aids.

NCSU Model: This model [18] was developed at North Carolina State University (NCSU). The model relates the throughput of a section of road to the volume and composition of traffic entering the section. There are three stochastic inputs to the model, namely desired speed of the vehicles, headway distributions and overtaking behaviour when any given gap has a probability of being accepted or rejected. The simulation process is time based. The main drawbacks of the model are:- (i) the input speed and desired speed in the test section are assumed to be identical and (ii) no account is taken of horizontal curvature.

Taylor, Miller and Ogden [29] model is used to establish warrants for provision of crawler lanes on uphill grades. Downgrade traffic stream was not modelled as no overtaking was permitted.

Stock and May [27] model represents only one direction of traffic flow in microscopic detail, whereas oncoming stream is modelled as distribution of gaps moving at uniform speed. Only cars are permitted to overtake according to an empirical gap acceptance distribution and in favourable traffic conditions. Speeds are not varied with road geometry.

Indo-Swedish Model [10] is quite comprehensive and based on large scale data collection about overtaking behaviour and speed distributions. All types of overtaking manoeuvres have been considered. The desired speed is related to road width, horizontal curvature, speed limit and gradient. The roadway is divided into homogeneous sections. Traffic is divided into four classes which consists of cars, trucks/buses, moving vehicles and motor cycle/scooter. slow/ The scanning is event oriented. The model is fully validated. The main drawback of the model is the amount of field work required as input. The model requires as input the observed speed and headway distributions.

MRI Model [16]: This model was developed by St. John and Kobett at Midwest Research Institute (MRI) under the National Cooperative Highway Research programme. The major objective of this study was to model and simulate traffic

flow on a two lane highway so as to determine the performance capabilities of vehicles, to determine equivalency factors for low performance vehicles, and to determine the role that performance and size play in traffic instabilities, accidents and loss of capacity. The entering time headways are based on Schuhl's distributions. The distribution of desired speeds in horizontal curves is related to curve geometrics. The probabilities of accepting an overtaking opportunity are related to speed of the leading vehicle and to passing opportunity distance. The computer simulation was also used to test the effects of vehicle dimensions and effects of changes in percent no passing facility. The traffic behaviour has also been evaluated for over width vehicles like mobile home and modular house loads with widths of 3.6 and 4.2 metres.

1.2.3 Signalized Intersection Models

These traffic model have special isolated aim of finding the effects of traffic on vehicles movement, such as delay and queue lengths . A few of these models are briefly reviewed below.

An example of simulation model is described by Daniel and Huber [6] for signalised intersection. This model simulates only for straight moving vehicles and for fixed time signals. The model does not consider the vehicle movement sequence either before they enter the intersection or after they are processed through the intersection, but they are generated and inserted into the queue . Then they are

discharged from the signal queue according to Greenshields [8] starting delay values which are given in Table 1.1.

TABLE 1.1: GREENSHIELDS STARTING DELAY FOR DISCHARGING VEHICLES FROM QUEUE HEAD

Position in Queue at Start of Green(M)	Time from start of Green until arrival at entrance of the intersection(in secs.)
1	3.8
2	6.9
3	9.6
4	12.6
5	14.2
6	$14.2+2.1(M-5)$

Various figures of merit used are, individual vehicle delays, maximum delays, average delay over all vehicles, average delay category wise, degree of saturation, load factor and maximum queue length.

Lewis and Michael [23] developed a simulation model to obtain volume warrants for intersection control. In this model they simulated a four legged intersection with fixed time signals. Delay was used as the figure of merit to obtain volume warrants. The vehicles were processed at the intersection using a car following model. They used the concept of release points to calculate vehicular delay.

Satyanarayana Reddy [24] developed a simulation model for signalized intersection for mixed vehicular traffic. Vehicles were not moved but discharged from the queue head into which vehicles were entered on generation, using observed starting delay in the field. The starting delay used were different for four wheelers and two wheelers. The starting delay used are as shown below.

TABLE 1.2 : STARTING DELAYS FOR FOUR WHEELERS IN INDIA

Serial number of vehicle	Starting delay
FIRST	4 seconds
SECOND	8 seconds
THIRD	11 seconds
FOURTH	14 seconds
FIFTH	16 seconds
SIXTH	18 seconds
----	----
----	----
----	----

TABLE 1.3 : STARTING DELAYS FOR TWO WHEELERS IN INDIA

Starting delays in seconds	Number of vehicles entering the intersections		
	Scooters	Rickshaws	Bicycles
3	5	4	9
8	8	8	17
13	11	12	25
18	14	16	33
23	17	20	41
28	20	24	49
-	-	-	-
-	-	-	-

Since the model did not move the vehicles it could not consider the effects of road quality and width in vehicular movement. Deceleration and acceleration of vehicles at intersections are not considered. The release points taken for delay calculation is arbitrary . Queue concept adopted near the signals also seems to be not correct.

It is seen from a cursory survey of literature that analytical and simulation models did not take into consideration at times vehicles do stop on roads for one reason or the other. In intersection models many/researchers have taken indirect approach by assuming starting delays thus circumscribing the need for vehicular movement which includes stopping.

1.3 PRESENT WORK

Traffic flow on open roads was modelled with the assumption that vehicles are uninterrupted by signals at intersections, narrow bridges, random busstops and any such other situations. This assumption is relaxed by introducing stopping logic required, not only at intersection but for many other situations prevailing in Indian traffic. The vehicle movement sequence in terms of acceleration, deceleration and stoppage conditions are modelled in an attempt to impart more realism.

The effect on the other vehicles when a vehicle stops in front of them is either to pass it if no overtaking restriction is there or to stop behind it forming a queue. This situation is captured by building a queuing model.

The usefulness of a model with the capabilities of depicting acceleration, deceleration and stoppages in traffic movements has significant potential as an analysis tool for design and operation of the traffic facilities. The application of the present model has been explored and suggestions for implementation of them are given.

1.4 ORGANISATION OF THESIS

In this chapter a detailed description of traffic models with brief survey of different traffic models was given.

The following chapter discusses the simulation approach to the analysis of traffic engineering related problems. Several

simulation languages available is discussed with emphasis on language SIMULA-67, the one which has been used in this thesis.

The third chapter describes methodology followed in developing the vehicle stopping logic as well as their sequence of movement and description of the Indo Swedish Road Traffic Simulation Model (ISRTSM) in which the stopping logic capsuled, is given.

Penultimate chapter lists the input and output of the model.

Description of the results obtained from the model and scope for further research are outlined in the final chapter.

The four appendices contains, the description of important procedures of ISRTSM, the flow chart of the present work, list of new procedures added and procedures changed in ISRTSM for present work and event file details.

CHAPTER II

COMPUTER SIMULATION APPROACH

2.1 WHY SIMULATE?

The major problem with the analytical models is that as the level of detail in the data is increased, it becomes more difficult to formulate equations-let alone solve them. Greater the number of input variables to be included, the more each will have to be approximated and generalised. If conditions at a given site are described only in generalised and compact form, then it is unlikely that the model can differentiate between before and after conditions relating to some small improvement.

Unless a fine level of detail can be input, the resulting information is only of limited value. So fully comprehensive analytical model is not a feasible proposition. Traffic flow modelling for Indian conditions is quite complex because of its heterogeneous nature consisting of different types of vehicle, in terms of speeds and physical dimensions. Also each maneuver made by a driver results from a decision sequence which is defined by variables having large random components. It is difficult to produce a realistic analytical traffic model for even homogeneous traffic. Hence the use of simulation methods for traffic flow analysis is natural and expected to play a significant role in solving problems related to design and operation of traffic facilities.

2.2 WHAT IS SIMULATION?

Digital computer simulation may be defined as 'a numerical technique for conducting experiments with certain types of mathematical models which describe the behaviour of a complex system on a digital computer over an extended periods of time' (Naylor, [17]). Simulation serves different functions in system analysis and design. They include

- (1) Aids in problem formulation,
- (2) Gives insight into the sensitivity of design to wide ranges of parameters,
- (3) Guidance in predicting system performance,
- (4) It is useful to validate the component models,
- (5) Data can be generated and used to study the transient and steady state characteristic of the system (Reitman, [22]).

There are generally a number of steps in simulation of an engineering system. Though the details may vary from time to time, a number of steps are common to several simulation studies. Figure 2.1 is the representation of the various steps of simulation (Naylor, [17]).

- (I) Formulation of Problem: The problem is formulated in analytic terms. It includes the identification of the system and its environment. Constraints of the system are also to be identified.

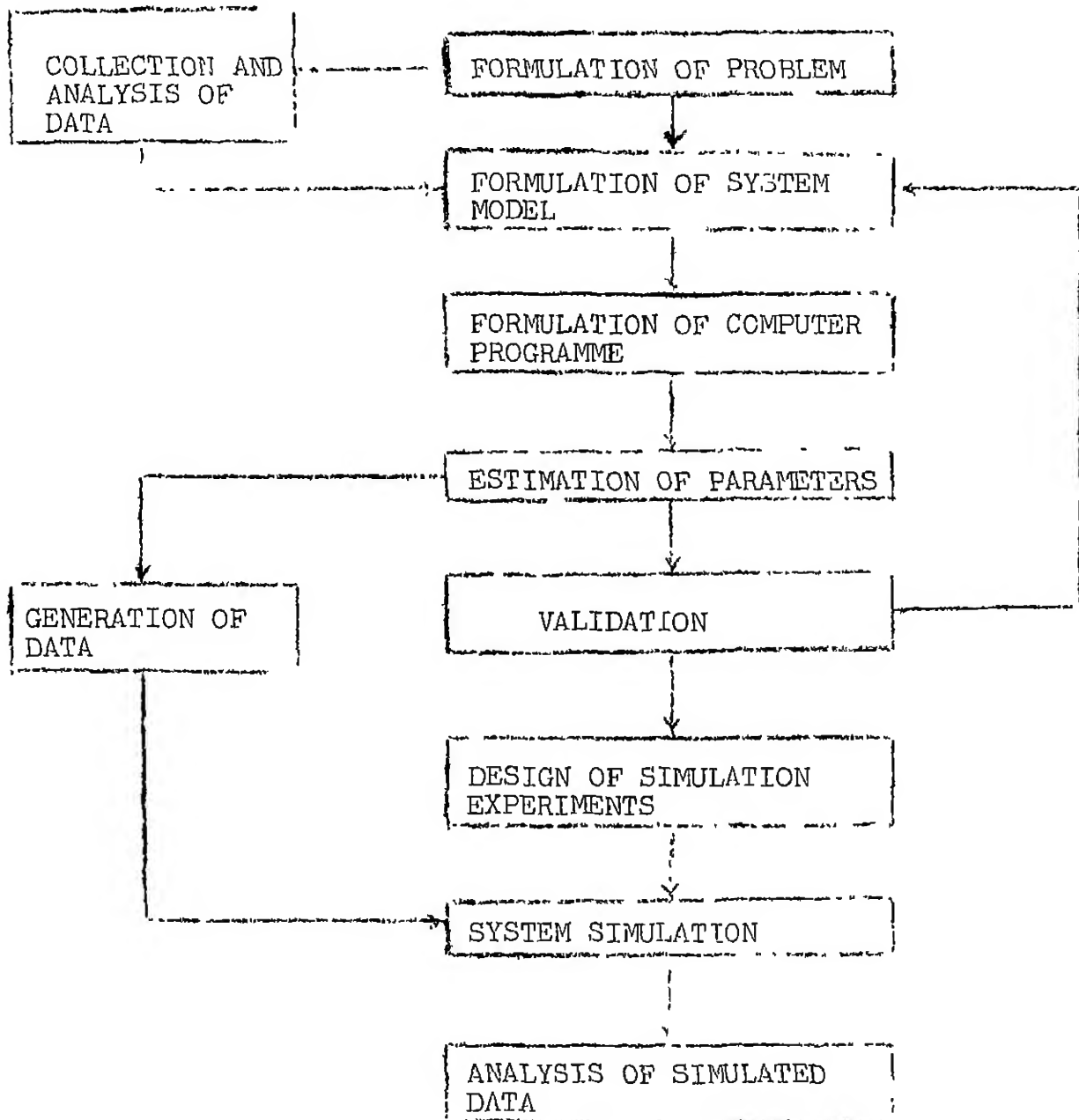


FIG. 2.1 : FLOW CHART FOR SIMULATION

- (II) Collection of data: Historical and experimental data concerning socioeconomic, engineering and other factors are collected and analysed.
- (III) Formulation of the system model: Based on experience, available knowledge and information, a system model is formulated to represent the components of the system, their parameters and behaviour and their relationships, the nature of the inputs to the system, throughputs, and outputs.
- (IV) Formulation of a computer programme: The formulation of a computer programme for the purpose of conducting simulation experiments with a model of a complex system requires special considerations to the following three activities (i) computer programme, (ii) data input and starting conditions and (iii) data generation.
- (V) Estimation of parameters: Parameters of the systems are estimated using historical and/or experimental data.
- (VI) Validation: The assumed mathematical model for the system is a simple approximation to a more complex reality. It is necessary to validate the assumed system model in order that the mathematical model is a reasonable approximation to reality. Validation involves the definition of reality and a reasonable approximation to it. Generally validation is done on the basis of comparison between the actual recorded output and the output from

simulation model for corresponding inputs. In case the model is considered to be unsatisfactory, it is necessary to modify the model suitably in order that estimated output from the model agrees with the observed record.

- (VII) Design of simulation experiments: Simulation may have to be done for analysis and optimisation of complex systems under different conditions of system inputs and outputs and values of design variables, if any. The values of these variables are generally to be sampled. Hence it may be necessary to select factor levels and combination of factors and the order of experimentation. It is also necessary to ensure that sampling errors are within bounds.
- (VIII) System simulation: The system is simulated under different conditions as per the experimental design. When random process are involved it may be necessary to generate and use data concerning such variables.
- (IX) Analysis of simulated data: Results from simulation are analysed to determine the characteristics of various components of the process, their significance and interdependence. A near optimal design may be obtained in appropriate cases.

2.3 SIMULATION LANGUAGES: (Mitrani [15])

One does not really need a simulation language in order to simulate. Any general purpose programming language can be used, with a greater or lesser degree of effort. What the simulation languages aim to do is to make life easier for the programmer by including some of the standard simulator components as language primitive. The facilities that a good simulation language should provide fall into five broad categories: They are

- A. Entity manipulation: Creating new entities, destroying old ones, placing entities into, and removing them from, ordered and unordered sets (stacks, queues etc.).
- B. Time and event manipulation: Maintaining a clock and an event list, and executing the scheduling operations.
- C. Random numbers: Sequences of numbers that appear to behave like independent and identically distributed random variables. Various discrete and continuous distributions should be provided, as well as the ability to both reproduce and change the sequence between different runs of the same program.
- D. Collection of statistics: Data that can be used to obtain means, variances, frequency- histograms and other quantities of interest. The collection may extend over entire simulation runs, or it may be restricted to separate portions of them.

E. Numerical computation : The ability to implement various numerical algorithms is required, e.g., in the statistical analysis of simulation output and in the construction of special random number generators. In addition, a good simulation language should possess all those qualities that are desirable in any programming language, such as power, flexibility, simplicity, ease of use, readability, modularity, efficiency of computation, run time efficiency, good diagnostics etc. Some of the popular simulation languages are SIMSCRIPT, GPSS and SIMULA.

2.4 SIMULA

Although originally intended as a special purpose simulation language, SIMULA is now a very powerful general purpose language (Dhal & Nygaard [5], Bitwistle et.al.[1]), structure of SIMULA can be loosely described by the following pyramid.

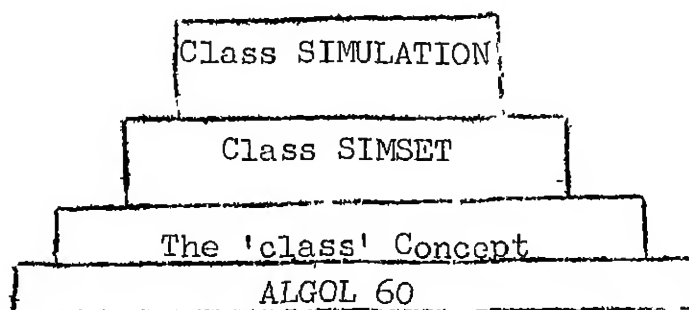


FIG.2.2 : SIMULA PYRAMID

At the base of the pyramid is the (very slightly modified) general purpose programming language ALGOL 60. A major addition

to that is notion of 'class', which allows one to define composite objects containing both data and actions. Two system defined classes follows. SIMSET and SIMULATION. The first provides facilities for manipulating linked lists and and second a clock routine, an event list and parallel processes. Using classes one can construct complex hierarchial data and program structures, that is, one can define other classes using the existing facilities and providing ones of one's own. A block prefixed by such a class can use both the old and new facilities.

2.5 COMPARISON OF SIMULATION LANGUAGES

The three popular simulation languages viz., GPSS, SIMSCRIPT and SIMULA are compared here under the following broad headings. generality, convenience and efficiency. Being tied to the concept of block diagrams imposes significant constraints on the genarality of GPSS. There are, for instance, certain state-dependent operations that do not lend themselves readily to description by block diagrams: e.g. multiserver queues with preemptive priorities or breakdowns, or system where service rate depends upon number, who are waiting for service. Such systems are difficult or impossible to simulate in GPSS. The inability to implement arbitrary numerical algorithms is also a significant disadvantage. SIMSCRIPT and SIMULA are completely general both from the simulation and from the numerical point of view.

On the otherhand, GPSS is the easiest of the three languages to learn and use. Program written in it tend to be shorter and easier to debug. The production of reports is automatic, although inflexible. SIMULA is perhaps more difficult than SIMSCRIPT to learn, but once learnt it is easy to use. A point in SIMULA'S favour is that its philosophy supports and encourages the use of structured programming and top down design techniques. A point in SIMSCRIPT'S favour is that its statistics collection facilities are more comprehensive. SIMSCRIPT is also more widely available than SIMULA and its compiler is cheaper.

GPSS program tend to be slower than SIMSCRIPT ones, which, in turn, tend to be slower than SIMULA programs. So faster, easy to use, language SIMULA, which has scope for structuring programme is used in present work.

CHAPTER III

MODELLING OF VEHICLE STOPPING AND STARTING FLOW SEQUENCE IN THE 'ISRTSM' AND ITS APPLICATIONS

3.1 MODEL DEVELOPMENT

Stopping logic modelling consists of representing deceleration stoppages and acceleration maneuvers when vehicles encounter signals and similar other spots. The vehicles will start building up queues in such situations. This aspect of queuing has been modelled in the queuing sub-model. For vehicle to become part of such queue it has to be affected by impediment of halting vehicle. The complete flow logic has been developed in the microscopic model framework.

3.2 SELECTION OF TRAFFIC MODEL FROM A SET OF MODELS

As presented in review of literature there are several traffic flow simulation models. Some of them use simple car following model for the movement of vehicles others take into consideration stochastic nature of driver decisions in various maneuvers.

Since stopping of vehicles is necessary at intersections and such other similar situations along the road, it has been felt that there is necessity of modelling to represent vehicle movement in such situations. Since vehicular stoppages are more prevalent on Indian rural roads than in any western

countries, this modelling needed to be incorporated in such a traffic flow model which depicts Indian conditions, and which is highly developed.

One such model which is highly developed and validated for Indian conditions is 'Indo-Swedish Road Traffic Simulation Model' (ISRTSM) developed jointly by I.I.T. Kanpur and National Road and Traffic Research Institute (VTI), Sweden. So the above model is chosen for incorporation of stopping logic.

3.3 DESCRIPTION OF INDO-SWEDISH ROAD TRAFFIC SIMULATION MODEL

The indo-Swedish road traffic model is a discrete event simulation model which tries to depict the behaviour of a traffic stream by considering in detail the behaviour of individual vehicles as they traverse a given section of the road. The model is stochastic with respect to gap acceptance under overtaking situations. The position of all the vehicles on the road is continuously examined on an event basis. An event can be thought of as each time a decision is required of a driver.

The model considers four categories of vehicles normally found on roads. Car group, HMV, two wheelers, Animal driven vehicles (ADV) have been considered for their behaviour in the traffic stream. The program system is shown in the Fig. 3.1. The road description over which traffic flow is to be simulated is fed into a road making program called 'SIMLU'. This divides

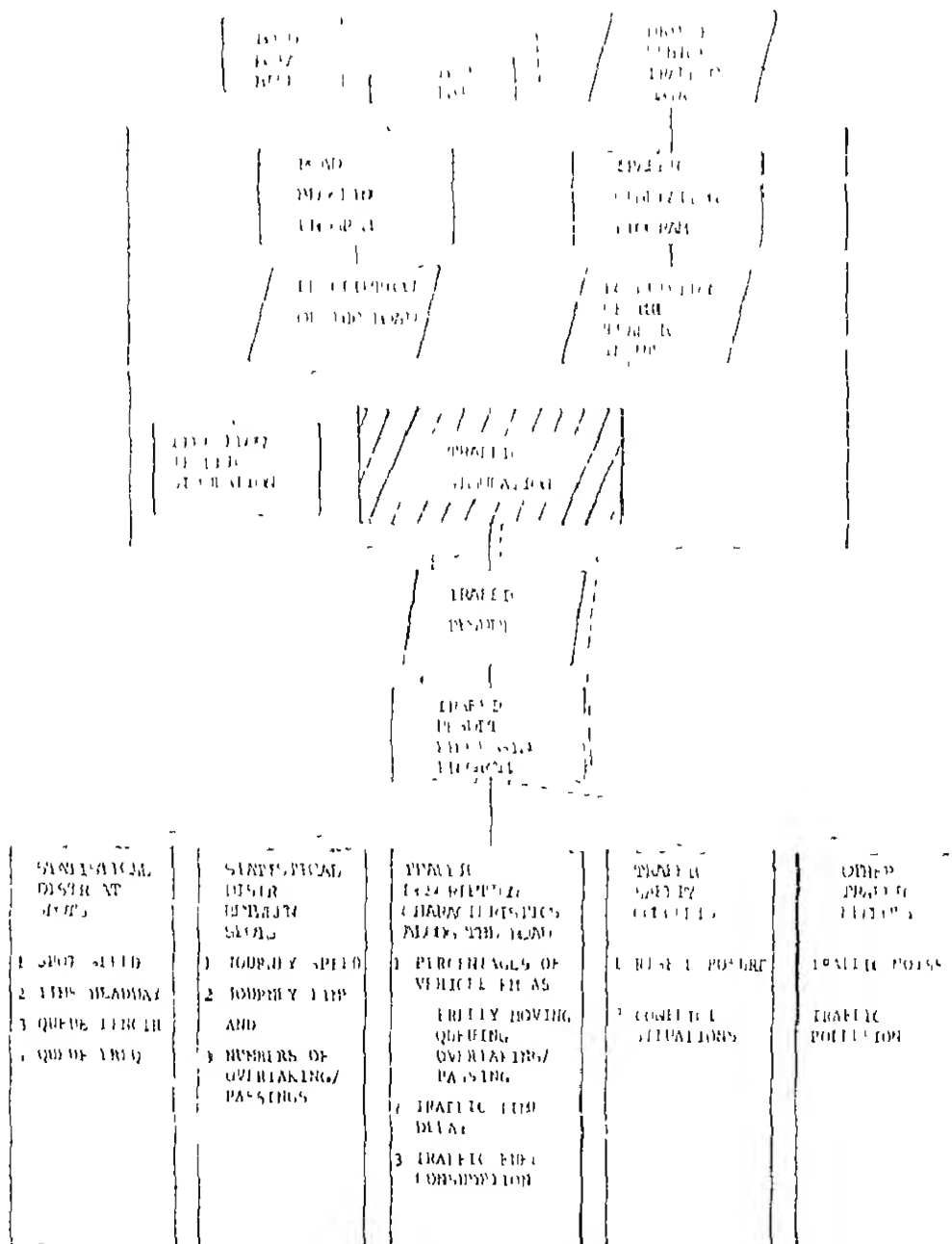


Fig 3) The position of the simulation program in the program system.

the road into homogeneous block with respect to free block speed, roughness, sight distance etc. The number of blocks is usually 25. It is possible to make more blocks if one desires.

The traffic is generated by both simple and complex traffic generation programs. These programs use the following parameters.

1. Total flow (number of vehicles/hour) .
2. Flow in each direction .
3. Flow changes .
4. Partial flow of heavy vehicles(traffic composition).

For the present work vehicles are generated using random traffic generation model proposed by Gillian and Johnson [7]. This program has been written in Fortran and has been used to generate traffic upto 1000 vehicles per hour in increments of 100 vehicles/hour in each direction.

The Indo Swedish simulation model requires that following traffic characteristics are assigned to each vehicle/driver combination entering the road stretch.

1. Vehicle type .
2. Power/weight ratio .
3. Basic desired speed.
4. Position within the platoon for those vehicles travelling in platoon.

5. Entry speed.

6. Time headway.

3.3.1 Power/Weight Ratios

Each vehicle is defined as belonging to one of the four vehicle types viz. Car, HMV, Two wheeler and Animal drawn vehicle. A separate marginal distribution of power/weight ratios was calibrated for each vehicle type. The power of a vehicle/driver combination is the maximum power which the driver is both willing and able to use.

The model used in the simulations to predict the effect of a gradient i on the speed of a vehicle of mass m is

$$m \frac{dv}{dt} = F - F_1 - F_r - mgi$$

where, v = speed of the vehicle at time t

F = Tractive force

F_1 = Air friction force (drag)

F_r = Rolling friction forces

$$m \frac{dv}{dt} = \frac{P}{v} - C_1 AV^2 - C_r m - mgi$$

where, P is the power of the vehicle at time t and C_1, C_r, A - are constants.

$$\text{or } \frac{P}{m} = v \frac{dv}{dt} + \frac{C_1 AV^3}{m} + C_r v + giv.$$

Integration now yields,

$$\frac{P}{m} = \frac{1}{t_1} \int_0^{t_1} P/m \, dt$$

or
$$\frac{P}{m} = \frac{1}{2t_1} (v_1^2 - v_0^2) + 1/t \left(\frac{C_1 A}{m} \right) \int_{S_0}^{S_1} v^2 ds$$

$$+ \frac{C_r (S_1 - S_0)}{t_1} + \frac{gh}{t_1} \quad (3.1)$$

where the left hand side of the equation is the mean power/weight ratio between S_0 and S_1 and t_1 is the time taken between S_0 and S_1 . These power/weight distributions for all the four types of vehicle have been given in Table 3.1 and plotted in Fig. 3.2, 3.2a, 3.2b.

3.3.2 Basic Desired Speeds:

Five main factors affect the speeds of vehicles on two lane roadways.

1. Driver characteristics.
2. Vehicle characteristics.
3. Load conditions.
4. Traffic regulations.
5. Traffic conditions.

TABLE 3.1: P-VALUE DISTRIBUTIONS FOR EACH VEHICLE TYPE
(For Swedish Conditions)

P(W/kg)	Percentage of vehicles accumulated			
	Type 1	Type 2	Type 3	Type 4
1	0.	0	0	0
2	0	0	0	0
3	0	0	1.0	3.5
4	0	0.9	6.0	23.0
5	0	3.1	20.4	45.6
6	0.4	12.6	39.5	63.4
7	0.4	24.8	57.2	79.3
8	1.0	39.7	71.4	88.9
9	2.1	48.7	85.7	96.3
10	4.2	64.3	91.6	98.8
11	4.6	78.4	96.7	99.7
12	8.1	85.3	99.5	100.0
13	9.8	93.0	99.8	
14	13.7	97.0	100.0	
15	22.5	98.8		
16	30.2	98.9		
17	40.3	99.0		
18	50.2	99.1		
19	60.4	99.4		
20	71.2	99.6		

Contd.....

Table 3.1 contd....

P(W/kg)	Percentage of vehicles accumulated			
	Type 1	Type 2	Type 3	Type 4
21	79.3	99.7		
22	86.4	99.8		
23	89.6	99.9		
24	91.2	100.0		
25	91.6			
26	95.2			
27	96.1			
28	96.1			
29	96.1			
30	97.9			
31	98.2			
32	98.6			
33	98.6			
34	98.6			
35	99.3			
36	99.3			
37	99.3			
38	100.0			

TABLE 3.1(a) : P-DISTRIBUTION FUNCTIONS FOR VARIOUS VEHICLE CLASSES

(For Indian Conditions)

$p\left(\frac{w}{kg}\right)$	Cumulative Percentage Frequency		
	Cars	Buses	Trucks
1	1.0	0.0	1.0
2	2.5	2.0	12.5
3	8.5	6.8	40.0
4	17.5	62.5	55.0
5	32.0	86.5	67.5
6	48.0	94.0	79.5
7	66.0	96.5	88.0
8	77.5	98.0	94.0
9	85.0	99.0	98.0
10	90.5	100.0	100.0
11	94.5		
12	97.5		
13	98.5		
14	99.5		
15	100.0		

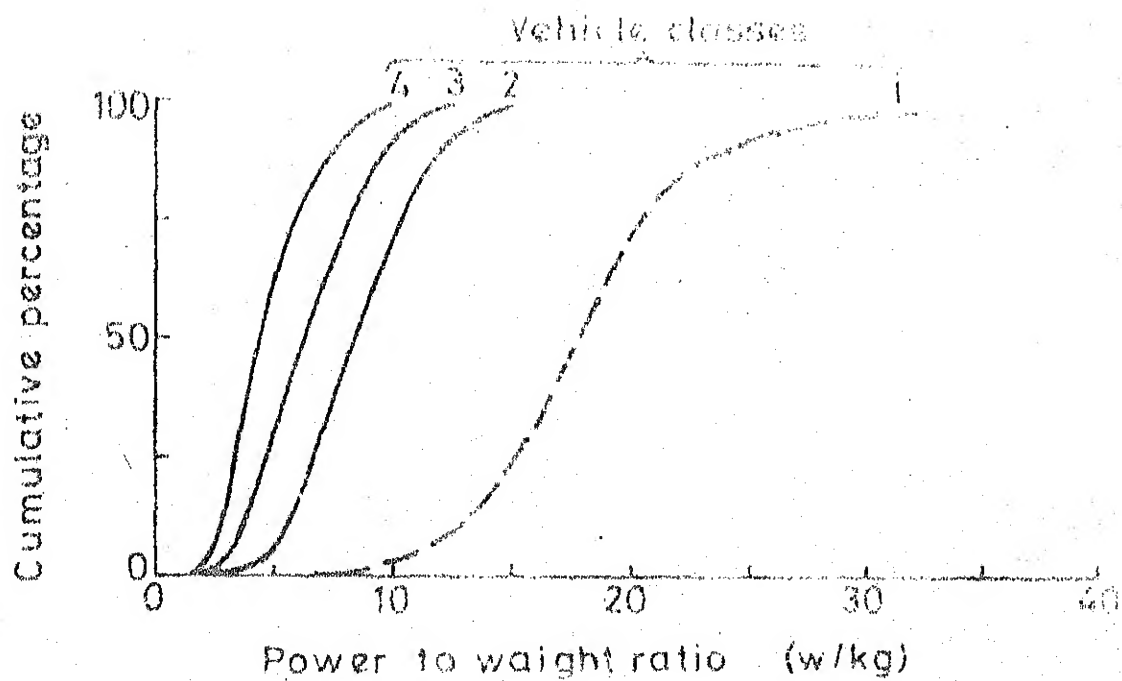


FIG. 3.2 p DISTRIBUTIONS FOR EACH VEHICLE CLASS
(For Swedish conditions)

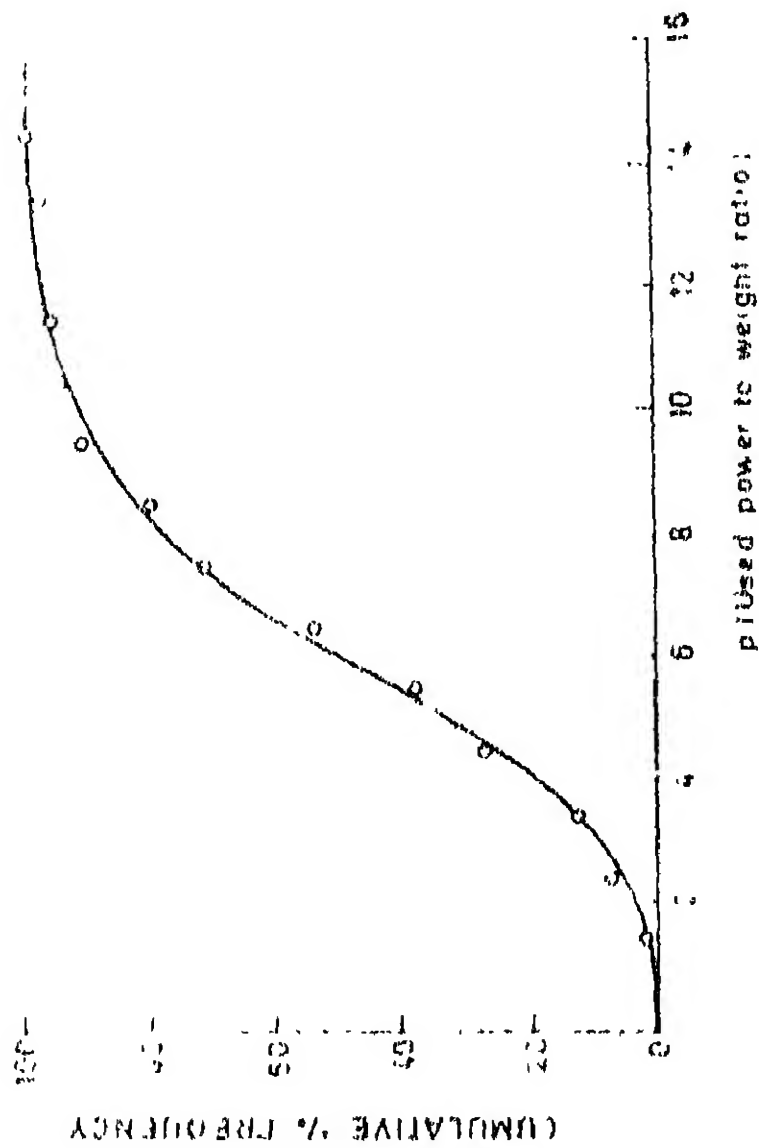


Fig 32ap(USED POWER TO WEIGHT RATIO) DISTRIBUTION FOR CARS
(For Indian Conditions)

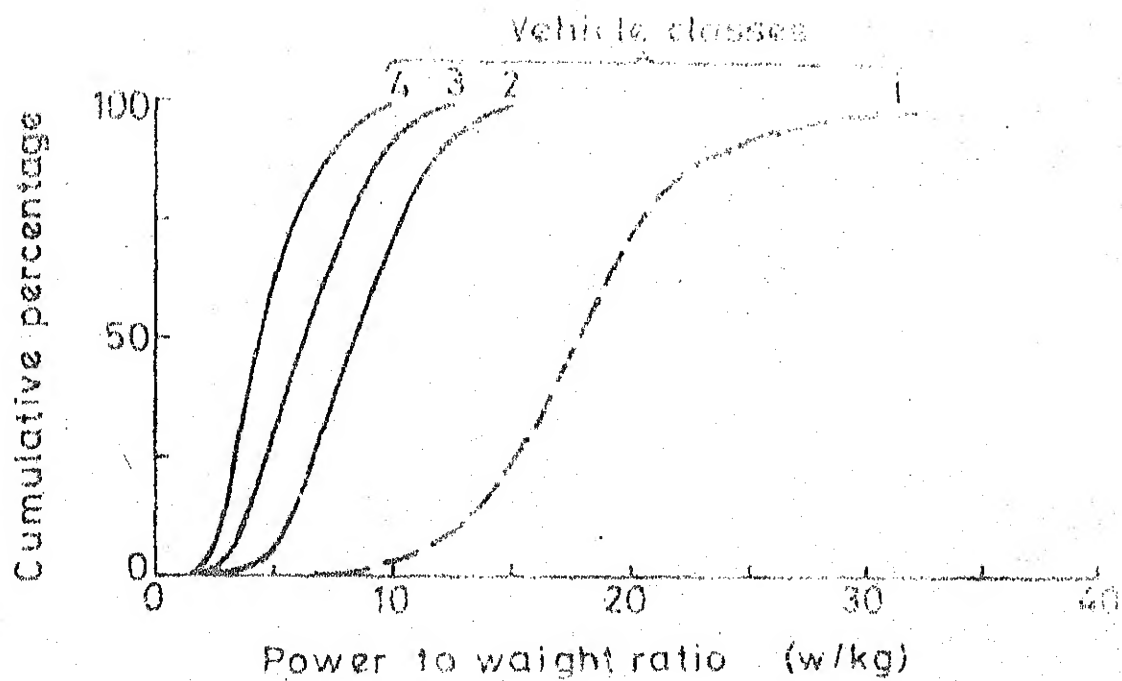


FIG. 3.2 p DISTRIBUTIONS FOR EACH VEHICLE CLASS
(For Swedish conditions)

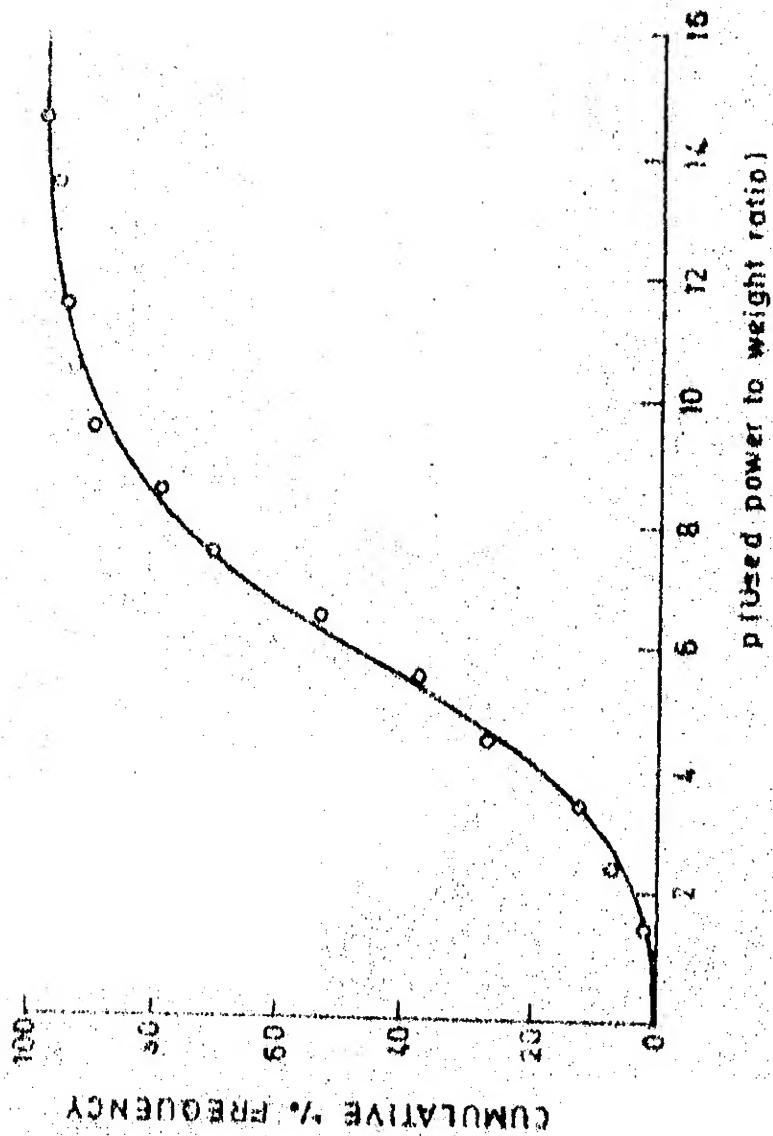


Fig 32a p (USED POWER TO WEIGHT RATIO) DISTRIBUTION FOR CARS
(For Indian Conditions)

Basic desired speed is the speed with which the vehicle/driver combination would maintain, were it not affected by any adverse road and traffic conditions or traffic regulations. Basic desired speeds are ideally measured on straight, wide, flat, two-lane roads under free flow conditions and with no speed limit. The observed distribution was approximated by normal distribution. The speed classes are given in Table 3.2 and plotted in Fig. 3.3.

3.3.3 Position within Platoon and Time Headways:

The time headway model used is a composite one as used originally by Schuhl [25]. This means that there are two separate time headway distributions for free moving and constrained vehicles respectively.

The usual form of the composite distribution (probability density function) is

$$f(t) = (1 - \alpha) g(t) + \alpha h(t) \quad (3.2)$$

where, $f(t)$ is the probability density function of the composite headway distribution, $g(t)$ is the probability density function of the headway distribution for free moving vehicles, $h(t)$ is the probability density function of headway distribution for constrained vehicles, α is the proportion of constrained vehicles.

TABLE 3.2 : BASIC DESIRED SPEED DISTRIBUTION-FAST MOVING
VEHICLES (FOR INDIAN CONDITIONS)

Speed class in 4 per- centiles	Speed of Cars (Vehicle type 1) m/s	Speed of Bus/Truck (Vehicle Type 2) m/s	Speed of 2 wheelers (Vehicle Type 4) m/s	Speed of All vehi- cles m/s
1	12.50	11.94	9.86	10.14
2	12.64	13.19	10.42	11.11
3	13.33	13.89	10.83	11.81
4	14.02	14.17	11.25	12.36
5	14.58	14.58	11.53	12.78
6	14.86	14.86	11.81	13.33
7	15.42	15.28	11.94	13.60
8	15.97	15.56	12.22	14.03
9	16.25	15.97	12.50	14.31
10	16.67	16.11	12.78	14.58
11	17.08	16.39	13.19	14.86
12	17.36	16.67	13.33	15.28
13	17.64	16.94	13.60	15.56
14	18.05	17.22	13.89	15.97
15	18.33	17.51	14.17	16.11
16	18.61	17.64	14.44	16.53
17	18.89	17.92	14.53	16.94
18	19.44	18.19	14.86	17.36
19	19.72	18.61	15.13	17.64
20	20.00	18.89	15.55	18.19
21	20.69	19.31	15.83	18.75
22	21.25	19.72	16.39	19.17
23	22.36	20.28	16.94	20.00
24	23.47	21.11	18.75	21.11
25	25.50	23.75	22.36	25.00

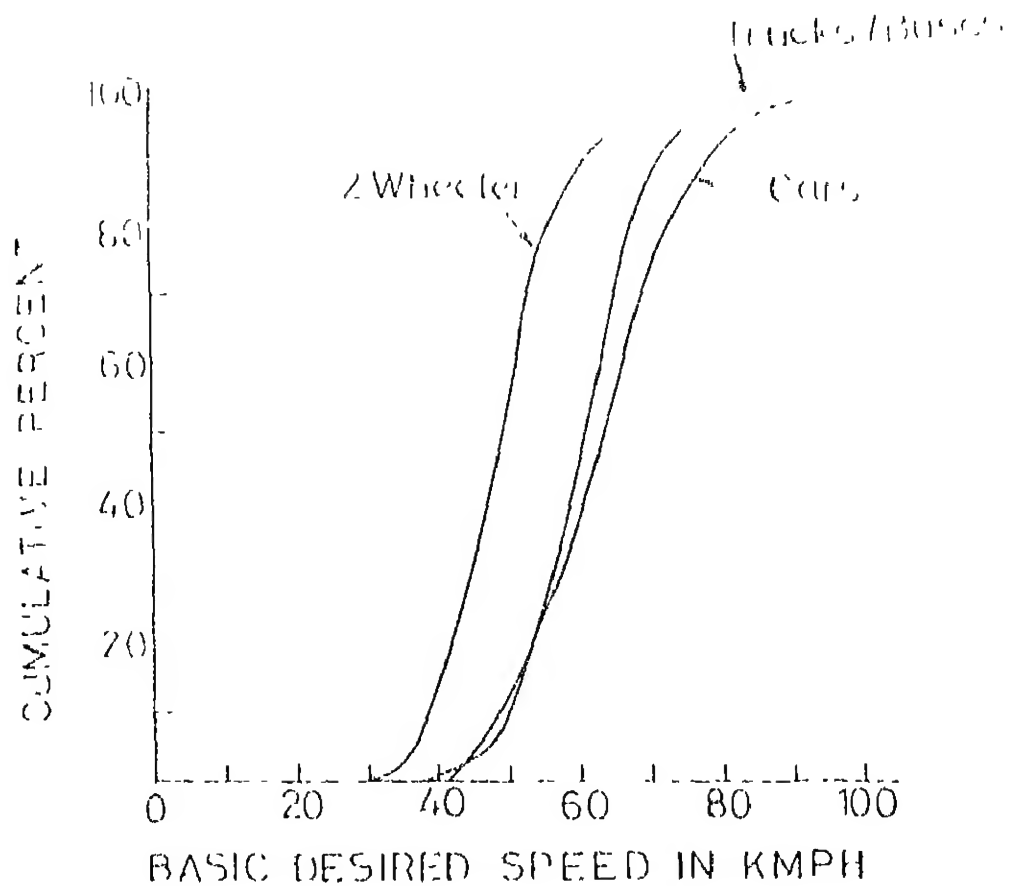


FIG 33 BASIC DESIRED SPEED DISTRIBUTION
(For Indian Conditions)

TABLE 3.2(a): THE V_0 DISTRIBUTION FUNCTION
(FOR SWEDISH CONDITIONS)

Speed class	$V_0(n)$ (m/sec)	Speed class n	$V_0(n)$ (m/sec)
1	18.20	14	27.30
2	20.35	15	27.75
3	21.47	16	28.20
4	22.32	17	28.68
5	23.04	18	29.19
6	23.64	19	29.74
7	24.16	20	30.34
8	24.64	21	31.00
9	25.11	22	31.72
10	25.56	23	32.66
11	26.00	24	34.29
12	26.43	25	37.50
13	26.86		

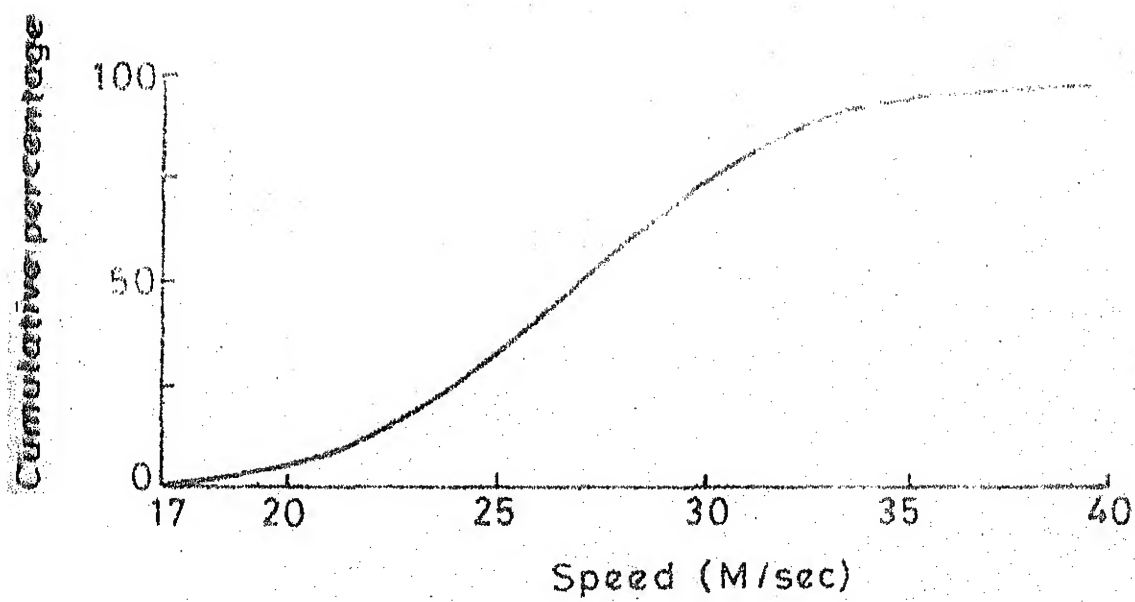


FIG. 3.3a V_0 - DISTRIBUTION
(For Swedish conditions)

The log normal and exponential distributions have been used to represent the time headway distributions of constrained and free-moving vehicles, respectively.

3.3.4 Time Headway Distribution for Constrained Vehicles (Log-normal):

Branston [2] has analysed constrained time headways on two way roads in Indiana, U.S.A. He found that a log normal distribution fitted the data with mean of 2 seconds and a standard deviation of logarithms of constrained headways σ_c of 0.45.

3.3.5 Time Headway Distribution for Free Moving Vehicles (Exponential):

This distribution is completely determined by mean μ_f . Now the total headway for a platoon length η is the sum of one headway for a free moving vehicle and $(\eta-1)$ mean headways for constrained vehicles. Hence, taking expected values,

$$\frac{\mu}{q} = u_f + (u-1) \mu_c \quad (3.3)$$

where, q is the following traffic flow

μ is the mean platoon size

μ_c is the mean headway for constrained vehicles.

3.3.6 Platoon Size Distribution:

Estimating the parameters m and S is equivalent to estimating the mean platoon size, u , and the expected proportion of platoon size 1, δ . This is because

$$\mu = \frac{(m+S+1)}{m} \quad (3.4)$$

$$\text{and } \delta = \frac{(m+1)}{(m+S+2)} \quad (3.5)$$

and this pair of equations can be solved for m and s .

Miller [14] has shown empirically that

$$\frac{1}{\mu} < \delta < \exp \left(- \frac{(\mu-1)}{\mu} \right) \quad (3.6)$$

and from their data it seems reasonable to approximate δ by the estimate

$$\delta = \frac{1}{2} \left(1/\mu + \exp \left(- \frac{(\mu-1)}{\mu} \right) \right) \quad (3.7)$$

Further more Miller [14] found that

$$u = 0.58 + 1.58Z \quad (3.8)$$

$$\text{where, } Z = \frac{0.1 q}{\lambda(1-qu_c)}$$

where, λ is the overtaking rate for constrained vehicles.

The problem of estimating μ is therefore reduce to that of estimating for a given road and traffic flow. Miller[14]

has used data collected on a single straight two lane road in Sweden to produce the estimate.

$$\lambda = 2750 Q^{0.62} \quad (3.10)$$

where, Q is the oncoming traffic flow.

The observed following traffic flow, q and observed proportion, θ of the time headways less than 4.8 seconds were used to estimate μ for each data set as follows.

$$\begin{aligned} P_{\gamma} (\text{Head} \leq 4.8) &= P_{\gamma} (\text{constrained vehicle}) \\ &\times P_{\gamma} (\text{constrained headway} \leq 4.8) \\ &+ P_{\gamma} (\text{free moving vehicle}) \times P_{\gamma} (\text{free moving} \\ &\text{headway} \leq 4.8) \end{aligned} \quad (3.11)$$

$$\begin{aligned} \theta &= \left(1 - \frac{1}{\mu}\right) P_{\gamma} (L(\mu_o^o) \leq 4.8) + (1/\mu) \\ &\times (P_{\gamma}(E(\mu_f) \leq 4.8)) \end{aligned}$$

Finally

$$\theta = \left(1 - \frac{1}{\mu}\right) \times 0.96 + \frac{1}{\mu} \left(1 - \exp\left(\frac{-4.8}{\mu/q - (\mu-1)2.4}\right)\right) \quad (3.12)$$

Given θ and q this equation may be solved for μ (for each data set) and hence λ may be estimated (for each data set), by substituting μ into equations (3.1).

3.3.7 Probabilities of Gap Acceptance:

The probability of accepting a gap of given length in order to overtake is required by the model in each of 32 different overtaking situations viz.,

Overtaking maneuvers	-	(1) Flying (2) Accelerative
Limitation	-	(1) On coming car (2) Sight distance
Vehicle overtaken		(1) Vehicle class 1, travelling at a speed < 72 km/hr. (2) Vehicle class 1, travelling at a speed \geq 72 km/hr (3) Vehicle class 2 (4) Vehicle class 3 or 4
Road width	-	(1) There exists a hard shoulder 2m or a climbing lane (2) Neither of this exists.

The following is the relationship for probability of gap acceptance.

$$P(X) = \begin{cases} 0 & \text{if } X \leq S_1 \text{ m} \\ a(X-S_1)/(S_2-S_1) & \text{if } S_1 < X < S_2 \text{ m} \\ 1 & \text{if } S_2 \leq X \text{ m} \end{cases}$$

where X is the gap distances and a , S_1 , S_2 are calibration constants.

3.4 DEVELOPMENT OF STOPPING ALGORITHM AND QUEUE SUBMODEL:

When it is decided to introduce stoppages in the traffic flow model, it is necessary to consider the situations where vehicles usually stop on roads. They stop usually near bridges, signals etc. Modelling of stopping near signals are more complex than modelling stoppages near narrow bridges, in the sense vehicles will stop near signals only when signal is red, where as in case of narrow bridges vehicles always stop .

In this study, stopping near signals have been modelled. For this simulation of signals were also incorporated in the original traffic model. The yellow period between red and green and green and red were merged to red and green respectively. The model has been structured so that it is capable of representing vehicles moving in yellow periods also.

Incorporation of signal simulation in the model included, introducing red to green or viceversa signal changes as the events in addition to the events already present in the model.

The simple logic followed for the above purpose is as given below.

If vehicle has stopped then:

Next event time is equal to, time when signal becomes gree plus, vehicle position in the signal queue times reaction time of the driver.

Otherwise:

Next event time is lesser of the predict next event time(as in the original model) and time when signal changes next plus vehicle position in signal queue times reaction time of the driver.

It is assumed that vehicles will decelerate from such a point, from where it can come to halt with maximum deceleration equal to 2m/sec^2 either on the stopline if it is first in the queue or behind another vehicle with sufficient gap between them if the vehicle is not first in signal queue.

Since the vehicles and driver unit in ISRTSM model, are considered as point object, to know how much should be spacing between vehicles when they have stopped, the dimension of different vehicles were essential. The assumed dimensions of different vehicles are given in the Table 3.3.

TABLE 3.3 : DIMENSIONS OF THE VEHICLES

Types of vehicles	Length (in mts)
1 Passenger car	4.60
2 Bus/Truck	9.35
3 Autorikshaw	2.75
4 Scooter and Motorcycles	1.90
5 Bicycles	1.90

In the representative road the signals are installed at places as shown below in Fig. 3.4.

For starting the vehicles from stoppage an initial velocity of 1.0 m/sec was assumed and the initial acceleration assumed was 1.00 m/sec^2 for faster vehicles and 0.75 m/sec^2 for slow moving vehicles. A vehicle will become member of signal queue if and only if it is affected by the signal, thus causing some delay when compared to its free flow conditions. A vehicle can be in signal queue both during red and green phases of the signal. This aspect is modelled as signal queue submodel.

The vehicles are discharged from the head of the queue and for this movement one should determine the position of the vehicle in signal queue. To do this a logic was developed which is as follows.

Let V_b be any vehicle

STEP1: If signal queue is empty position of V_b in queue = 0.

Go to step 12

STEP2: If V_b is first in signal queue position of V_b in queue = 1. Go to step 12

STEP3: If there is no vehicle behind first vehicle of the queue then position of V_b in signal queue = 0. Go to step 12

STEP4: Let V_{f2} refer to vehicle present behind first vehicle of the queue

[illegible]

1
2
3
4

()
()
()

1841-1842

1

()
 }
 }
 }
 }
 }
 }
 }

123
r
- 3
111
J
r
r-3
(3
(/1

$\frac{1}{2} \times \frac{1}{2} = \frac{1}{4}$

2
 3
 4
 5
 6
 7
 8
 9
 10
 11
 12
 13
 14
 15
 16
 17
 18
 19
 20
 21
 22
 23
 24
 25
 26
 27
 28
 29
 30
 31
 32
 33
 34
 35
 36
 37
 38
 39
 40
 41
 42
 43
 44
 45
 46
 47
 48
 49
 50
 51
 52
 53
 54
 55
 56
 57
 58
 59
 60
 61
 62
 63
 64
 65
 66
 67
 68
 69
 70
 71
 72
 73
 74
 75
 76
 77
 78
 79
 80
 81
 82
 83
 84
 85
 86
 87
 88
 89
 90
 91
 92
 93
 94
 95
 96
 97
 98
 99
 100
 101
 102
 103
 104
 105
 106
 107
 108
 109
 110
 111
 112
 113
 114
 115
 116
 117
 118
 119
 120
 121
 122
 123
 124
 125
 126
 127
 128
 129
 130
 131
 132
 133
 134
 135
 136
 137
 138
 139
 140
 141
 142
 143
 144
 145
 146
 147
 148
 149
 150
 151
 152
 153
 154
 155
 156
 157
 158
 159
 160
 161
 162
 163
 164
 165
 166
 167
 168
 169
 170
 171
 172
 173
 174
 175
 176
 177
 178
 179
 180
 181
 182
 183
 184
 185
 186
 187
 188
 189
 190
 191
 192
 193
 194
 195
 196
 197
 198
 199
 200
 201
 202
 203
 204
 205
 206
 207
 208
 209
 210
 211
 212
 213
 214
 215
 216
 217
 218
 219
 220
 221
 222
 223
 224
 225
 226
 227
 228
 229
 230
 231
 232
 233
 234
 235
 236
 237
 238
 239
 240
 241
 242
 243
 244
 245
 246
 247
 248
 249
 250
 251
 252
 253
 254
 255
 256
 257
 258
 259
 260
 261
 262
 263
 264
 265
 266
 267
 268
 269
 270
 271
 272
 273
 274
 275
 276
 277
 278
 279
 280
 281
 282
 283
 284
 285
 286
 287
 288
 289
 290
 291
 292
 293
 294
 295
 296
 297
 298
 299
 300
 301
 302
 303
 304
 305
 306
 307
 308
 309
 310
 311
 312
 313
 314
 315
 316
 317
 318
 319
 320
 321
 322
 323
 324
 325
 326
 327
 328
 329
 330
 331
 332
 333
 334
 335
 336
 337
 338
 339
 340
 341
 342
 343
 344
 345
 346
 347
 348
 349
 350
 351
 352
 353
 354
 355
 356
 357
 358
 359
 360
 361
 362
 363
 364
 365
 366
 367
 368
 369
 370
 371
 372
 373
 374
 375
 376
 377
 378
 379
 380
 381
 382
 383
 384
 385
 386
 387
 388
 389
 390
 391
 392
 393
 394
 395
 396
 397
 398
 399
 400
 401
 402
 403
 404
 405
 406
 407
 408
 409
 410
 411
 412
 413
 414
 415
 416
 417
 418
 419
 420
 421
 422
 423
 424
 425
 426
 427
 428
 429
 430
 431
 432
 433
 434
 435
 436
 437
 438
 439
 440
 441
 442
 443
 444
 445
 446
 447
 448
 449
 450
 451
 452
 453
 454
 455
 456
 457
 458
 459
 460
 461
 462
 463
 464
 465
 466
 467
 468
 469
 470
 471
 472
 473
 474
 475
 476
 477
 478
 479
 480
 481
 482
 483
 484
 485
 486
 487
 488
 489
 490
 491
 492
 493
 494
 495
 496
 497
 498
 499
 500
 501
 502
 503
 504
 505
 506
 507
 508
 509
 510
 511
 512
 513
 514
 515
 516
 517
 518
 519
 520
 521
 522
 523
 524
 525
 526

6
1
6
1
1

11 1 1
1 1 1
1 1 1
1 1 1

4
 5
 6
 7

4
5
6

- STEP5: If $V_b = V_{f2}$, go to step 8 otherwise go to step 6
- STEP6: If V_{f2} is last in queue, position of V_b in queue = 0.
Go to step 12.
- STEP7: Let V_{f2} refer to vehicle present behind previous V_{f2} . Go to step 5.
- STEP8: Position of V_b in queue = 2. Go to step 9
- STEP9: Let V_f refer to vehicle in front of V_{f2} . Go to step 10
- STEP10: If vehicle V_f is queue first then go to step 11
- STEP11: Let V_f refer to vehicle present ahead of previous V_f
- STEP12: Exact position of V_b in queue = position of V_b in queue.

The reaction time of drivers are assumed to be 2.5 secs.
The other assumption in the model is that, signal is situated only on the block border of homogeneous road block. The complete sequence of flow of vehicles obeying signal is programmed according to the following logic.

- STEP1: Check whether the vehicle has crossed signal post. If it has crossed go to step 3, else go to step 2.
- STEP2: Check the status of the signal. If the signal is red for the direction of travel, go to step 3, if green to step 18.
- STEP3: Check whether there is a vehicle in front of the present vehicle. If there is a vehicle go to step 4 else go to step 5.

STEP4: Check the position of front vehicle. If it has not crossed the signal post and is at such a position, it can come to halt with permissible deceleration then go to step 6 else go to step5.

STEP 5 If the present vehicle is the nearest one to signal post when signal turns green from red. Then go to step 6 else go to step 33.

STEP6: Check whether the vehicle can stop with permissible deceleration value thus responding the red signal for the direction of travel. If it can stop go to step 7 else goto step 15.

STEP7: Find out whether signal becomes green for the direction of travel before or by the time vehicle reaches such a point it starts decelerating to stop. If so goto step 18 else goto step 8.

STEP8: Move the vehicle upto a point from where it starts decelerating (stopping sight distance) and check whether by the time vehicle comes to half with reduced signal becomes green. If so go to step 17 else go to step 9.

STEP9: Make the vehicle to halt near the signal line. Enter this vehicle into signal queue of the direction and goto step 33.

STEP10: If the front vehicle has stopped goto step 12 else
if it has not stopped but is in moving condition
goto step 11.

- STEP11: Find whether the front vehicle is the last vehicle in the signal queue for the direction. If it is the last one goto step 12 else goto step 33.
- STEP12: If the vehicle is in overrestriction zone of the signal environment goto step 14 else go to step 13.
- STEP13: Find out distance between the present vehicle and the one in front of it. If they are very close goto step 14 else goto step 33.
- STEP14: Enter the vehicle into signal queue of the direction and goto step 33.
- STEP15: Increase the counter keeping count of number of vehicles moving in yellow period between red to green changes. Goto step 33.
- STEP16: Wait till signal becomes green and goto step 18.
- STEP17: Increase the counter keeping count of vehicles partially delayed by signals by one and goto step 33.
- STEP18: Find out whether there is queue built due to signal. If there is queue goto step 19 else goto step 22.
- STEP19: Increase the counter keeping account of number of signal cycles fully made use by vehicles by one and goto step 20.
- STEP20: Check whether front vehicle has stopped. If stopped goto step 17 else goto step 21.
- STEP21: Check whether the front vehicle is in such a position that it can come to halt with permissible deceleration. If it can stop goto step 26 else goto step 22.

STEP22: Check whether the present vehicle is nearest vehicle to signal post when signal turns red next. If so goto step 12 else go to step 33.

STEP23: Find out the position of the vehicle when signal turns red.

- (i) If the vehicle will be past the signal post by the time signal becomes red goto step 24.
- (ii) If the vehicle will be in such a position that it is the nearest one to signal post but can not stop with permissible deceleration then goto step 25.
- (iii) If the vehicle will be in such a position that it is the nearest one to signal post and can stop with permissible deceleration then wait until signal becomes red and goto step 3.

STEP24: Increase the counter keeping account of vehicle unaffected by signal and goto step 33.

STEP25: Increase the counter keeping account of vehicles moved in yellow period between green to red change and goto step 33.

STEP26: If the front vehicle is last in the signal queue of of the direction then go to step 27 else goto step 33.

STEP27: If the vehicle is in over restriction area of the signal environment then goto step 29 else goto step 28.

STEP28: Find out the distance between the current vehicle and the one in front of it. If they are very closely spaced then goto step 29 else goto step 33.

- STEP29: Enter the vehicle in the signal queue of the direction and goto step 30.
- STEP30: If the current vehicle halted then goto step 32 else goto step 31.
- STEP31: Increase the counter keeping account of vehicle discharged from signal queue in green period and goto step 33.
- STEP32: Wait till the current vehicle becomes the first vehicle of the signal queue and start the vehicle by giving it an initial velocity of 1.0 m/sec and goto step 33.
- STEP33: Move the vehicle as in the original Indo-Sweedish traffic model. Goto step 34.
- STEP34: Check whether vehicle has reached it's destination. If it has not reached then goto step 1 else goto step 35.
- STEP35: Check whether maximum vehicle generation time or simulation cut-off time has reached. If it has reached then goto step 36 else goto step 37.
- STEP36: Generate another vehicle and move the vehicle using the logic of step 1 to step 30.
- STEP37: Print the results and stop.

3.5 APPLICATION OF THE MODEL

3.5.1 Simulation of Signalized Intersections

Present model can be directly used to simulate signalized intersections. Such simulation will help engineers to

know whether the already fixed time of signals are performing at a desired level or there is need to change the timings. This can be determined by identifying measures of effectiveness. Some of the measures of effectiveness usually considered are (i) Proportion of delayed vehicles and delay times of different categories of vehicles (ii) Load factor or degree of utilization of the signal and (iii) Queue length of different categories of vehicles of various approaches. Also we can optimize signal timings.

We can also establish the effect of variation of signal timings and overtaking restriction zone lengths(usually dividers) on the queue lengths and utilization and delays for vehicles. We can also estimate increased fuel consumption due to effect of signals on the vehicles. Also we can determine the effect of increasing or decreasing overtaking restriction zone near intersection on fuel consumption, as fully validated fuel consumption model in ISRTSM is reported.

3.5.2 Establishing Volume Warrants:

Volume warrants are nothing but an index which indicate when to go for signalization of intersections. The present model can be used to simulate both unsignalized and signalized intersections with a bit of modifications.

We can establish volume warrants by simulating the same intersection with and without signals. The difference between the measure of effectiveness of two such experiments help in establishing volume warrants.

3.5.3 Simulation of Density Scanners:

Density scanners are one of the types of traffic controlling devices. These are traffic actuated unlike pre timed signals, here timing of red and green period gets adjusted proportional to the volume of traffic present on the approaches of intersections.

Usually for each vehicle entering the signal queue the green period increases. The entry of vehicles are scanned by electronic scanners. There will be fixed maximum green period beyond which the signal turns red for the approach. These types of signals are definitely better than preactuated signals, if one ignores the cost.

Such scanners can be easily simulated in the present model. With slight modification in the 'Procedure system signal' of the present model. At present green timing and red timings are fixed but this can be replaced by length of the signal queue times fixed increment of time in green period per vehicle. Signal queue length at any time can be referred by simula's built in attribute of doubly^{linked} list called 'cardinal'.

3.5.4 Simulation of System of Signalised Intersection and Unsignalised Intersections

The present model can be modified to simulate system of signalised and unsignalised intersections. The result of such simulation will be useful in fixing timings of signals of various intersection on entire network minimising the total delay of travel time.

The needed modifications in the present model are, the 'procedure action signal' should be converted to a class. The class will have the attributes, signal timings ie both red and green period and location of signal post, coordinates of overrestriction zone begining. The class can be called whenever signalized intersection is encountered in the movement of vehicle while it will follow usual logic of ISRTSM on other times.

3.5.5 Accident Model and Accident Analysis

The present model can be used to create accident of vehicles. Such modelling will help in accident analysis which in turn is essential for loss prevention of life.

Accident is said to occur in the model, if different vehicles occupy same coordinate at same time having same predecessor and successors.

In the original ISRTSM model at no time head and tail of vehicles are allowed to overlap. In the present model

with certain probability tail and head of vehicles can be allowed to overlap thus causing accidents.

The probability can be ascertained from field study and this can be allowed to occur at such places where casualty taking place regularly.

CHAPTER IV

INPUT AND OUTPUT OF THE MODEL

4.1 INPUT OF THE MODEL:

Input to the model consists of a road file, traffic file and model data. Road file is nothing but description of the road on which vehicle is to be moved. This is created by another program to which following field data are fed.

For each block in each direction

1. A coordinate for the beginning of each block in mts
2. Carriage width maximum 7m
3. Hard shoulder width in dm
4. Speed limit in km/h
5. Gradient in percentage
6. Curvature 10^4 m^{-1} (The curvature is the inverted value of the horizontal radius) following data describing sight
7. A coordinate for the beginning of each sight section in meters
8. Sight distance at this coordinate and the following data about overtaking restriction and hard shoulder
9. A code for over restriction
10. A code indicating hard shoulder/climbing lane presence.

Traffic file having following vehicle data:

1. Identify number
2. Vehicle type
3. Basic desired speed in m/s
4. P-value(Power/weight ratio) in w/kg
5. Direction
6. Coordinates for entry to and exit from the section
in meters
7. Time and speed at entry to the section

and the Model data mentioned below

- (1) Probabilities of overtaking at different coordinates
- (2) Time headways for different types of vehicles
- (3) Deceleration value
- (4) Rolling resistance
- (5) Air resistance coefficient
- (6) Probability of vehicle going to lane 3.
- (7) Extra speed in track 1 etc.

and following general data

- (1) Maximum vehicle generation time
- (2) Data collection points
- (3) Random number speed
- (4) Simulation cutoff time.

4.2 THE OUTPUT OF THE MODEL

The results from traffic flow models are printed in chronological order and are used for further processing. 18 types of situations are defined. Each time an equipage is in one of these situations the results can be printed. In 13 of the situations the result is always printed. If the result is to be printed when one of the remaining situations occurs, this must be specified at the start of the simulation.

Table 4.1 below shows different types of result, the situation for which they are printed and whether the result is obtained conditionally or unconditionally .

To illustrate further the frequently occurring event 14 is to be read as follows.

Event No.	Veh. identification No.	Vehicle in front	Original track number	Local coord	Local speed m/sec	Average speed	Predict bl border speed
14	53	None	2	1120	9.58	9.58	9.58
Local time	Predict next event time	Predicted block border time	Time	Status of flow	Signal status	Predict coord	Local Sp
240.00	240.97	240.97	240.73	Completely free	Signal green	1130	9.58
Average speed		Predicted	blborder	speed	Predicted time	blborder	
9.58		9.58				242.73	

Table 4.1 contd....

Information type	Occasion	Short description of result	
12	opportunity for accelerated overtaking not accepted	as for type 4	O
13	block border passage	equipage status, basic desired speed, equipage type and power/weight coefficient, energy consumption	B
14	every change	equipage status, predicted times and speeds, etc.	C
15	overtaking is interrupted before level point	equipage status	U
16	overtaking is finished after levelpoint	equipage status	U
17	following terminated	equipage status	U
18	overtaking level-point	equipage status, identity, coordinate, speed and type of 1) the overtaken and 2) the oncoming vehicle	L

+) equipage status refers to identify, road and time coordinates, speed and track

U = unconditional result
 B = conditional result
 O = conditional result
 L = conditional result
 C = conditional result after time specified.

CHAPTER V

RESULTS DESCRIPTION AND CONCLUSIONS

5.1 RESULTS DESCRIPTION:

In the present traffic model vehicles are moved depending on vehicular interactions, the quality of road on which vehicle is moving and the stochastic behaviour of drivers. The scanning or shifting of time takes place event wise.

Results are printed in event file, in detail giving account of every individual vehicular movement as and when an event occurs. The first few rows of the output contains the details of the input fed for simulation such as maximum vehicle generation time, name of the road file, coordinates of the data points at which data are collected for validation purpose, rolling resistance for different types of vehicle, deceleration value, air resistance, time headways for categories of vehicles etc. These are denoted by event number '0' at the start of a row.

First column of the event file denotes the event number on which account the status of the vehicle being output. The various events in the model are,

- 1) Entry of vehicle on a section of road.
- 2) passing block limits.

In the model, the road on which vehicles are moved are divided into specified number of homogeneous road blocks. Vehicles are moved from block to block in the absence of any other intermediary events.

- 3) Catching a preceding equipage.
- 4) Tailing begins.

If the fast moving vehicle meets the slow moving vehicle on the same track, there exists two alternative either to overtake or to adopt speed to tail the equipage. Taillength of the vehicles are given in seconds for different categories of vehicles.

- 5) Passing a maximum sight point

The sight distance along the road is approximated with a sectionally linear function. The point where this sight distance function has maximum is called maximum sight point. For accelerated overtaking, vehicle has to wait till they reach these points.

- 6) The equipage meets another equipage in on coming lane.
- 7) Overtaking begins.
- 8) Equipages level during overtakings.
- 9) Conclusion of overtaking when the overtaken equipage is not tailing .
- 10) Exit to hard shoulder/climbing lane .
- 11) Return from hard shoulder/climbing lane to normal lane .

12) An equipage is caught up.

In addition to their original events, the below events are introduced in the present work.

13) Signal becoming red .

14) Signal becoming green .

15) The point when vehicle starts decelerating due to the effect of signal.

16) The vehicle coming to stop .

17) The vehicle starting from stoppage.

The event file gives every detail of vehicle movement. For accomplishment of specific needs, the event file are further processed through specific post processing programme.

5.2 CONCLUSIONS AND SCOPE FOR FUTURE WORK:

In the present thesis the vehicular stoppage on roads and their starting has been modelled. The effect of such stoppage is queue formation and delay to vehicles. The queue formation has also been modelled.

The present thesis shows the need for stopping logic in the traffic model by exploring the possible benefits by indicating the applications of the logic. The model at present state has only shown the way the stoppage can be modelled. The stopping spot reconsidered in modelling is traffic signals. It is assumed vehicles stop with permissible deceleration, and certain fixed acceleration values are assumed at the start of vehicles. The road files used and signal timings assumed

and traffic files are fictitious.

Before model is fully put to its potential use the following works to be carried out.

- (1) For any simulation model to be used, it is to be validated. Since almost whole 'ISRTSM' model stands validated, the present sub-model needs validation.
- (2) In calculating stopping distance of the vehicles only deceleration acceptable was taken as criteria. However, stopping distance depends upon drivers behaviour (PIEV concept) , Efficiency of brakes, Frictional resistance between the road and the tyres and slope of road surface if any. A detail study should go on to define stopping distances of vehicles, taking all the above factors into considerations.
- (3) The composition of traffic and geometrics of the highway may be varied along with the period of signal and the effect of these factors on the figure of merits can be studied. In this model straight road way with ideal geometric features are assumed.
- (4) In the model vehicles have been assigned some predetermined fixed headways without taking the changes of headways during the interaction of vehicles at different speeds and the intensity of interaction (depending number of vehicle) into account.

- (5) Random nature of queue formation and queue dispersion near signals prevalent in Indian conditions should also be thought off and should be incorporated in the model.

REFERENCES

1. Birtwistle, G.M., Dahl, O.J., Myhrhaug, B. and Nygaard, K., 'SIMULA BEGIN' Van Nostrand Reinhold, New York, 1971.
2. Branston, D., 'Models of Single Lane Time Headway Distributions', Transportation Science Vol.10, No.2, (1976).
3. Brodin, A., 'VTI Traffic Simulation Model. A program for the Monte Carlo simulation of vehicle traffic along two-lane rural roads. An Application of JSP and SIMULA-67 Language', VTI, Bulletin No.322A, 1983.
4. Carter, E.C., Palaniswamy, S.P., 'Study of Traffic Flow on a Restricted Facility', Department of Civil Engineering, University of Maryland, College Park, 1973.
5. Dahl, O.J., and Nygaard, K., 'SIMULA- An ALGOL- Based Simulation Language', CACM, 1966.
6. Daniel, L. Gerlough, Mathew, J. Huber, 'Traffic Flow Theory- A Monograph', Special report 165, TRB, 1975.
7. Gillian, C.D., 'A Model for the Generation of Various Traffic Characteristics', MAV NOTE. 259, 1978.
8. Green Sheld, B.D., Shapiro, D. and Ericksen, E.L., 'Traffic Performance at Urban Street Inter Sections', Yale Bureau of Highway Traffic, Conn, Tech. rep.1 (1974).
9. Haight, F.A., 'Towards a Unified Theory of Road Traffic', Operation Research, Volume 6, No.6, 1958, pp. 813-826.

10. Indo-Swedish Road Traffic Simulation Model. A draft report submitted to CRRI, New Delhi, 1983.
11. Janoff, M.S., and Cassel, A., 'Identification and Evaluation of Remedial Aid Systems for Passing Maneuvers on Two-lane Rural Roads', Volume-IV, Federal Highway Administration, Research and Development Report, 1970.
12. Kometani, E., 'On the Theoretical Solution of Highway Traffic Capacity Under Mixed Traffic', Memoirs of the Faculty of Engineering, Kyoto University, Volume 17, 1955, pp. 79-98.
13. Lighthill, M.J., Whitham, G.B., 'On Kinematic Waves, II' 'A Theory of Traffic Flow on Long Crowded Roads', Proceedings of Royal Society London, Series A, Volume 229, No. 1178, 1955, pp. 317-345.
14. Miller, A.J., 'A Queueing Model for Road Traffic Flow', Journal of Royal Statistical Society, Series B, Volume 23, No. 1, 1961, pp. 38-63.
15. Mitrani, I., 'Simulation Techniques for Discrete Event Systems', Cambridge University Press, 1982.
16. MRI Model St. Jhon and Kobets, Midwest Research Institute, 1978.
17. Nayler, T.H., et al., 'Computer Simulation Experiments', John Wiley and Sons Inc., Newyork, 1966.

18. NCSU model, 'Simulation of Highway Traffic on Two-lane Two-way Rural Highways'.
19. Norman, O.K., 'Highway Capacity Manual', Washington, D.C., 1950.
20. Palaniswamy, S.P., 'Optimization of Traffic Flow Over a Restricted Facility', Ph.D. Dissertation, University of Maryland, College Park, 1973.
21. Paul Warnshuis , 'Simulation of Two-way Traffic on an Isolated Two-lane Road', Transportation Research, Vol.1, 1967, pp. 75-83.
22. Reitman, J., 'Computer Simulation Experiments', Jhon Wiely and Sons, Inc., New York, 1971.
23. Russell, M. Lewis, Harold, L. Michael, 'Simulation of Traffic Flow to Obtain Volume Warrants for Intersection Control', Highway Research Record, Number 15, 1963, pp.1-43.
24. Satyanarayana Reddy, B., 'Computer Simulation of a Signalised Intersection with mixed vehicular Traffic', M.Tech.Thesis, IIT Kanpur, 1976.
25. Schuhl, A., 'Probability Theory Applied to Vehicle Distribution on Two-lane Highways, in Poisson and other distributions in Traffic', Enofoundation for Transportation, Saugatuck, 1971, pp. 74-97.
26. Shumate, R.P., and Dirkson, J.R., 'A Simulation System for Study of Traffic Flow Behaviour', HRR 72, 1965, pp.19-39.

27. Stock, W.A. and May, A.D., 'Capacity Evaluation of Two-lane, Two-way Highway by Simulation Modelling', Transportation Research Record 615 (1976), 20, 27.
28. Tanner, J.C., 'Delays on a Two-Lane Road', Journal of Royal Statistical Society, Series B, Volume 23, No.1, 1961, pp. 38-63.
29. Taylor, Miller and Ogden Model of Simulation of Traffic Flow.
30. Wardrop, J.G., 'Some Theoretical Aspects of Road Traffic Research', Proceedings of the Institute of Civil Engineers Part 2, Volume 1, 2, Road Paper No.36, 1952, pp.325-362.

APPENDIX - A
DESCRIPTION OF IMPORTANT PROCEDURES
AND VARIABLES IN ISRTSM

THE ROAD

In the program the stretch of road considered consists of a sequence of consecutive road block objects and a sight distance function in each direction of travel. Each road block object is homogeneous with regard to the following road geometry and traffic regulation parameters:

1. Road width and road surface type
2. Auxiliary lane/lateral space (i.e. wide shoulder)
3. Slope
4. Horizontal curvature
5. Speed limit
6. Overtaking restriction

The road block is represented in the program as an object from the class ROADBLOCK. This object has the following attributes:

I Location and length

RCCO coordinate of road block beginning
RBLLENGTH road block length

II Road geometry and traffic regulation attributes

ROADWIDTH road width class
LANE occurrence of auxiliary lane/lateral space
RI slope
RQ Q value
DVQ block speed for median equipage ** RQ - basic
 desired speed for median equipage ** RQ
RNOFOVRI code relating to overtaking restriction

III References

PSIGHTMAX occurrence and coordinates of sight
 distance maximum
PSIGHTREF reference to distance length function

The road block object is linked in each direction in a SIMSET list with the headings DIRECTION1 and DIRECTION2 respectively.

The sight distance at different points along the road is approximated with a linear function of the road coordinate. One function is required for each direction of travel.

The sight distance function is represented for direction 1 in the program by coordinate pair (BPTAKPCOORD1), SIGHTDISTA(1) and in a corresponding way for direction 2.

To facilitate determination of the sight distance at an arbitrary point along the road, the road block has here, as mentioned above, been given a reference to the sight distance function in the same direction.

PSIGHTREF=n if $S_n \leq RCO < S_n + 1$ where S_n and $S_n + 1$ are road coordinates for two consecutive breakpoints and WK is the road coordinate of the road block beginning.

III EQUIPAGE

Equipment attributes and vehicle behaviour

In the program, the equipage is represented as an object of the class `EQUIP`. The object has the following 8 options (E*) or 6 compulsory (C*) attributes:

I Administrative attributes

<code>IDPRU</code>	E*	identity number
<code>DIRECTION</code>	E*	direction number
<code>ORIGREF</code>	E*	coordinate of the road for start of equipage
<code>CWMPACT</code>	C*	Track number
<code>DEST</code>	E*	coordinate of the road for termination of equipage
<code>DESTDIR</code>	E*	destination reached

II Driver-vehicle attributes

<code>VOM</code>	E*	basic desired speed
<code>TIMEHEADWAY</code>	E*	time headway
<code>MINTIME</code>	E*	shortest stay in auxiliary lane/lateral space after passing
<code>PNORMAL</code>	E*	power/weight coefficient allotted
<code>P</code>	C*	Calculates the p-value for the vehicle. If the vchtype is 1 (private car) and in track, 1 then the vehicle receives a stronger p-value in this case. $P = \begin{cases} 30 & \text{if } PNORMAL \leq 2.5 \\ PNORMAL + 7.5 & \text{if } PNORMAL > 2.5 \end{cases}$ otherwise $P = Pnormal$
<code>VEHICLETYPE</code>	E*	vehicle type

C2	LX	air resistance coefficient
C1	LX	rolling resistance coefficient
W	EN	accumulated energy consumption

III Traffic attributes of the equipage

FOLLOWING	FN	equipage is following
BEHCAATCHUP	FN	equipage is caught up
LOCALCOORD	FN	road coordinate at preceding event
LOCALTIME	EN	time of preceding event
LOCALSP	EN	speed at preceding event
AVERSP	FN	speed from preceding event to next event
PREDICT - NEXTTIME	LN	predicted time of next event
PREDICT - BORDERTIME	FN	predicted time of passage of next road block border
PREDICTBI BORDERSP	LN	predicted speed at passage of next road block border
FREEBLSP	EN	free block speed

IV References

BLOCK	EN	reference to actual road block
-------	----	--------------------------------

The events are assumed to occur momentarily at calculated times. At each event the model data is updated and a particular event generated from among the possible consecutive event types. A note of the predicted event is inserted chronologically and logically in a list (SQS) and the events are then executed in this order.

The ordinary cycle for an arbitrary equipage is:

1. Predict the time of the next event - PREDICTNEXTTIME
2. Await the predicted time - HOLD -
3. Move the equipage in time and space - DRIVE -

During phase 1 of the cycle, each EQUIPAGE calculates $FOURTHWAY$, $AVLWSP$ and $PREVIOUSOVERSP$ as follows in procedure TIMELOC. During phase 2 of the cycle, the procedure TIMELOC updates the attributes $LOCALHAW$, $LOCALCOWAY$, $LOCALV$, $AVLWSP$, $PREVIOUSOVERSP$ and $PREVIOUSLLEADSP$.

During phase 3 of the cycle, each EQUIPAGE calculates $AVLWSP$ and interacts with the current equipage with the result that the predicted time of the next event for this equipage is the minimum of times it will occur either. Its ordinary cycle is consequently interrupted and the current equipage concludes that a "surprise" has occurred through the SURPRISE procedure. A procedure $AVLWSP$ calculates $AVLWSP$ of the equipage in this mode.

Each equipage has been allocated a "head" and a "tail". This equipage constantly attempts to drive so that their heads do not overlap their tails. The lengths of the heads and tails are defined as:

$$\text{head length} = \frac{(AVLWSP - AVERSP)^2}{2 \cdot FAC} \quad \text{if } AVLWSP > AVERSP$$

$$0 \quad \text{otherwise}$$

$$\text{tail length} = \text{TIMEHEADWAY} \cdot AVERSP$$

where $AVLWSP$ is $AVERSP$ for a preceding equipage. Head length therefore indicates the distance required to slow down with given retardation FAC to the speed of the preceding vehicle. The tail length is chosen so that equipages in a queue are separated by given time interval.

An important aspect of the program is that a road is divided into a number of lanes, where each equipage in each lane behaves in a defined manner.

Direction of traffic:	----- 3	Direction of traffic:
a) → right-hand traffic	1 ----- 2	a) → right-hand traffic
b) ← left-hand traffic	2 ----- 1	b) → left-hand traffic
	3 -----	

An equipage can use three of the four lanes. Lane 2 is the ordinary lane in the direction of travel and lane 3 is a wide shoulder or auxiliary lane. In lane 1 priority is given to traffic in the opposing direction.

An equipage remains in its lane until it decides to change lanes. The reason for this decision may be in order to overtake, i.e. move out into lane 1 or alternatively move onto lane 3 to allow a catching-up faster equipage to pass.

Short description of equipage procedures

To acquaint the equipage as to which of the many complicated situations is in force, a number of procedures and variables are provided.

These situations are listed and described below. A brief description of the predicting routines i.e. the procedures which, among other things, calculate the time to a given next event, is also provided. The latter procedures are similar in that they all give a time to the next block border if this event type occurs before the given event.

Variables controlling behaviour

Basic routines

PREDICTCOORD	calculates the road coordinate for current equipage at the particular time (i.e. at TIME)
PREDNS(B)	Calculates the road coordinate for equipage B at the particular time (i.e. at TIME)
PST(VEH, T)	Calculates the road coordinate for equipage VEH at time T
VEHBACWITRK(X)	Calculates a reference to an equipage in track x travelling behind

VEHEQUALTRK(X)	Calculates a reference to an equipage alongside in track x
VEHFORWITRK(X)	Calculates a reference to preceeding equipage in track x
PLATOONLEADER(VO)	Calculates a reference to a platoonleader for the equipage vo.
ONCOMINGVEHEQUAL ORBACKWITRK(X)	Calculates a reference to an equipage in track x travelling alongside or behind in oncoming traffic stream.
ONCOMINGVEHFORW ITRK(X)	Calculates a reference to preceeding equipage in track x in oncoming traffic stream.
LASTVEHINONCOMING PLATOON(X)	Calculates a reference to last equipage in track x in oncoming traffic stream.
PASSING(X)	Decides whether own head or tail overlaps that of another equipage in track x
STARTPOSSIBILITY	Decides whether start possibility applies. Start possibility if head or tail of own equipage does not overlap that of another equipage in lane 2 or lane 3
CHANGETOTRACK(X)	Move own equipage to track x
BEHINDVEAFFECTED	Decides whether equipage travelling behind in the same lane needs to be reactivated
VEHINTRK1AFPEC	Decides whether equipage in track 1 needs to be reactivated.
REACTFORW	Reactivates preceeding equipage
REACTBACKW	Reactivates next equipage travelling behind in the same track.
REACTTRK1VEH	Reactivates the nearest equipage whose tail lies behind the current equipage
CONSTRAINED	Decides whether the current equipage is following
INTERESTING	When an equipage is reactivated the procedure INTERESTING decides whether the equipage is in track 1 or track 2 and is being caught up by another equipage
ACC(SPEED)	Calculates acceleration ability at SPEED

BEABTOFOLR	Decides whether a preceding equipage is "close" and the speed is less than the free blockspeed. "Close" defines the distance between the head of the current equipage and the tail of the preceding equipage as being less than 1.5 times the tail length of the preceding equipage
------------	---

Routines in conjunction with catching up

CATCHINGUP(X)	Decides whether the current equipage catches up another equipage in track x before passing the next road block limit
---------------	--

VEHOBJCATCHING- UP(VO)	Decides whether equipage VO catches up a preceding equipage before passing the next road block border
---------------------------	---

CATCHINGUPBEF- PREDICTNEXTEV- TIME(VB)	Decides whether equipage VB catches up the current equipage before VB's PREDICTNEXT-EVTIME
--	--

Routines in conjunction with overtaking or passing

MAXSIGHTPNT	Decides whether an overtaking opportunity exists. An overtaking opportunity exists if maximum sight length exists in the road block and the distance between the equipage and the point of maximum sight length is less than 3 m.
-------------	---

RENDEZVOUSQRMAX-
SIGHT

FLYINGOVTAK- ACCEPT	Decides whether an opportunity for overtaking is accepted
------------------------	---

ACCOVERTAKING ACCEPTED	Decides whether an opportunity for accelerated overtaking is accepted
---------------------------	---

ABLE	Decides whether the vehicle has sufficient acceleration ability to carry out an overtaking. More exactly estimated length of the overtaking is less than sightlength x constant
------	---

WANT

A random number is drawn and gives "true" with a specified probability. This probability depends on:

- 1) Accelerated/flying overtaking - OMT
- 2) Vehicle type and whether a private car is taken into consideration when average speed is less or greater than 20 m/s
- 3) Road width class - VB
- 4) Visible/invisible meeting
- 5) Sight length

VACANT

Decides at point of decision for accelerated or flying overtaking whether it is possible to change track to track 1, i.e. whether track 1 is occupied by another equipage

ALLOW

Decides whether the vehicle is permitted to carry out an overtaking. Permission is given if no overtaking prohibition applies and if no unbroken white line exists. The driver is looking for overtaking restriction min (300, estimated length of the overtaking x constant) m ahead.

TIRED

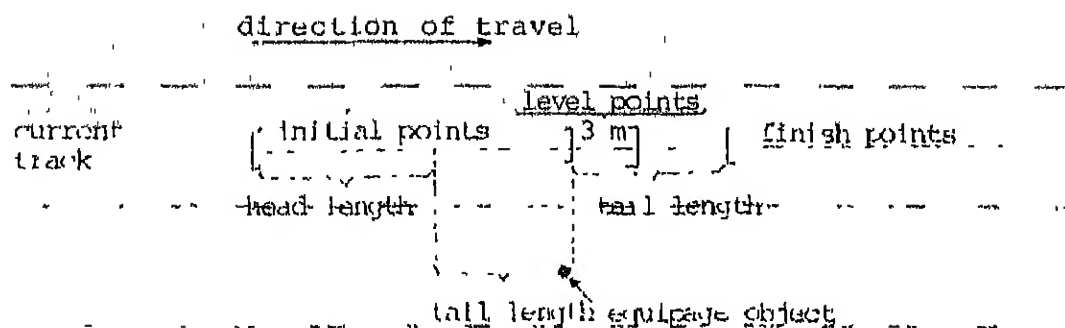
Decides whether the equipage abandons its attempts at overtaking. The probability of this is at present 0

OBJINSAMETRACK

True if the head of the current equipage overlaps the tail of the preceding equipage in the same track

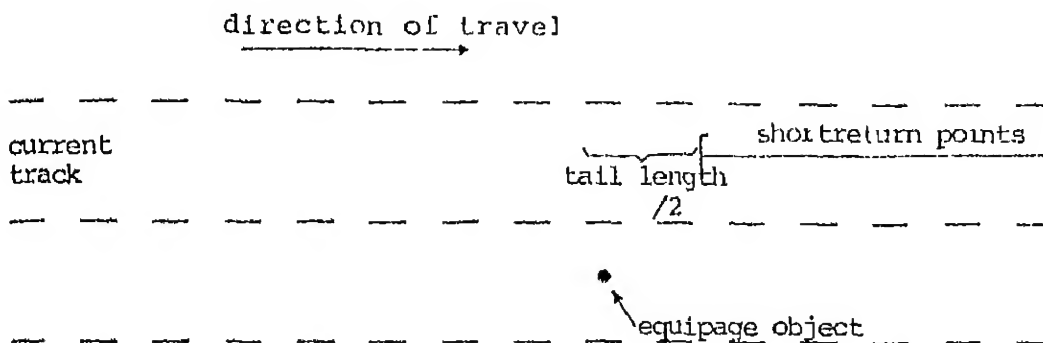
INITIALPOINTS,
LPNT,
FINISHPNTS

Decides upon overtaking or passing whether initial points, level points or finishing points apply



SHORTRETURN

Decides upon overtaking whether short return applies



OVERTAKING-CONTINUE

Decides whether an overtaking is to be completed. Is completed when the equipage has greater speed than the overtaken equipage.

NEWOVERTAKING

Decides whether a new overtaking is likely, implicates that the driver wants to overtake and the vehicle is permitted and has sufficient acceleration ability to carry out an overtaking. Note that this makes NEWOVERTAKING true if no new overtaking is likely.

SCATCHINGUP1

Decides upon completing an overtaking of equipages in a platoon, but not the platoon leader, that the current equipage catches up another equipage in the current track before overtaking is completed.

Routines in conjunction with the equipage being passed

VACANTANDWANT-TOGOTOTRACK3

Decides when the current equipage is caught up in track 2 whether it can and wants to change track to track 3.

CANRETURN

Decides whether the current equipage in track 3 can return to track 2.

Predictive routines

TRAVEL

Apart from the block speed, an average slope is assigned to each block. Each equipage also has a power/weight coefficient, P , which determines its ability to reach its block speed, given the particular slope.

The TRAVEL procedure tests this ability by inserting values in the power equation:

$$a = \frac{P}{v} - c_a \cdot v^2 - c_b$$

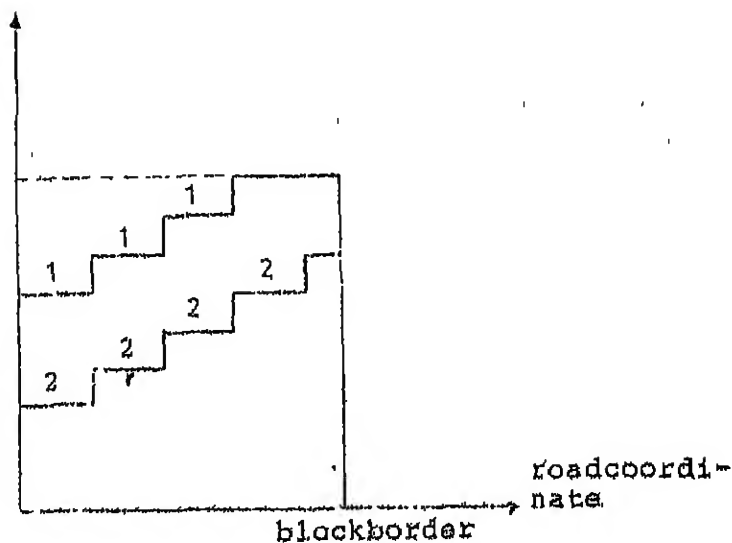
where

- a = acceleration m/s^2
- p = power/weight ratio W/kg
- v = speed m/s
- c_a = air resistance coefficient
- c_b = rolling resistance and "slope coefficients"

In this test v is set to the block speed. If acceleration thereby becomes less than 0 or the current speed is less than the block speed, PTS is inserted in the power equation. Otherwise calculation is made either with the same speed, TS, (time over road stretch) or with a uniform retardation, RETARD, depending on whether the particular speed is equal to or greater than the block speed.

PTS

free
block
speed



In procedure PTS there is a numeric integration of the power equation over time until either the free block speed has been exceeded (case 1 in the figure) or the blockborder exceeded (case 2).

Use is made of

$$a = \frac{dv}{dt} \text{ gives } v_t = v_{t-\Delta t} + \Delta t \cdot a$$

$$v = \frac{ds}{dt} \text{ gives } s_t = s_{t-\Delta t} + \Delta t \cdot 0.5 \cdot (v_t + v_{t-\Delta t})$$

where

a = acceleration

v = speed

s = distance

t = time

Integration step Δt (DELTA in PTS) is set to

$$\Delta t = k \cdot \text{PRECISION} \cdot \left| \frac{v}{a_0} \right|$$

where

k = a constant set to 3

PRECISION = required precision in integration

In the program PRECISION has been set to 0.5 %.
 v_0 and a_0 are speed and acceleration at the beginning

**TIMETOSTART-
POSSIBILITY**

Calculates time to start possibility.

**TIMETOBLOCK-
LIMIT(C)**

Calculates time to next block limit.
C indicates whether the current equipage is free or constrained.

Routines in conjunction with catching up

TIMETOCATCHU

Calculates time until the first of the following events:

- 1) Catching up equipage in track 3
- 2) Catching up equipage in track 2
- 3) Block limit

**TIMETOCATCHING
UPPOINT(X)**

If the equipage catches up another equipage in track x the procedure calculates the time to the catching up point.

TIMETOBEHCATCH Calculates time to the point where the current
UPPOINT(C) equipage is caught up. C indicates whether the
 current equipage is free or constrained.

Routines in conjunction with preparation for following

TIMETOFOLLOW When an equipage has decided not to carry out a
 flying overtaking the procedure calculates the
 time to the point where the equipage has slowed
 down and travels with a given headway from the
 preceding equipage.

Routines in conjunction with overtaking or passing

TIMETOOVERTAKACC Calculates the time to the point for an acceler-
 ated overtaking.

TIMETOINITIAL- Calculates the time to the point where the over-
POINTS(C) taking equipage is in level with the overtaken
 equipage. If the current equipage (overtaking) has
 a lower average speed than the overtaken equi-
 page the time to the block border is calculated.
 C indicates whether the current equipage is free
 or constrained.

TIMETOLPNT(C) Calculates the time to the point where the over-
 taking equipage is 3,3 m in front of the overtaking
 equipage. C indicates whether the current equi-
 page is free or constrained.

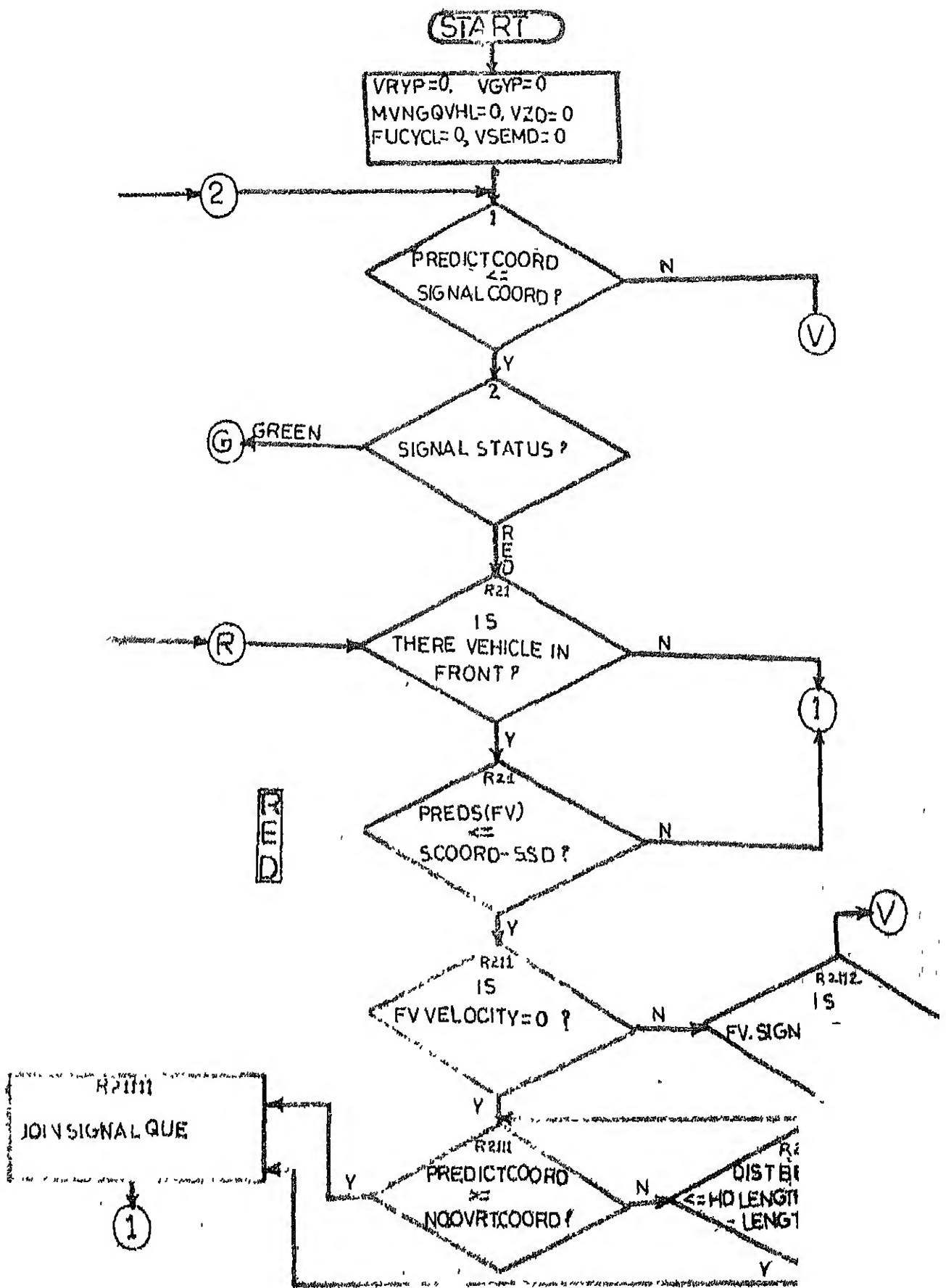
TIMETOFINISH- Calculates the time to the finish point in an
POINT(C) overtaking. If the overtaken equipage has a
 greater average speed than the current equipage
 the time to the next block border is calculated. C
 indicates whether the current equipage is free or
 constrained.

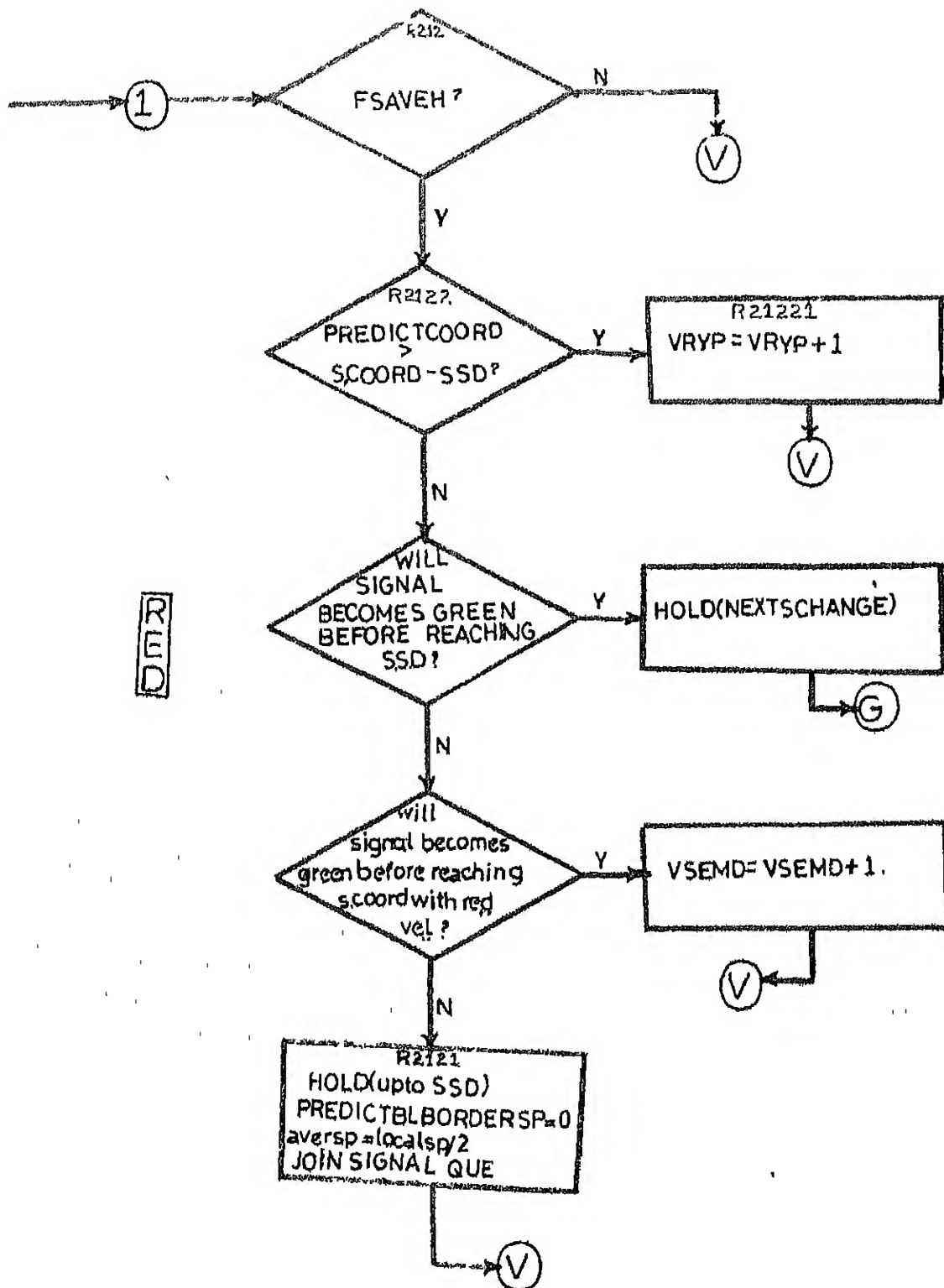
TIMETOSFINISH- Calculates the time to a short finish point in an
PNT(C) overtaking. A short finish point applies when the
 current equipage overtakes individual equipages in
 the platoon with the exception of the platoon
 leader. C indicates whether the current equipage
 is free or constrained.

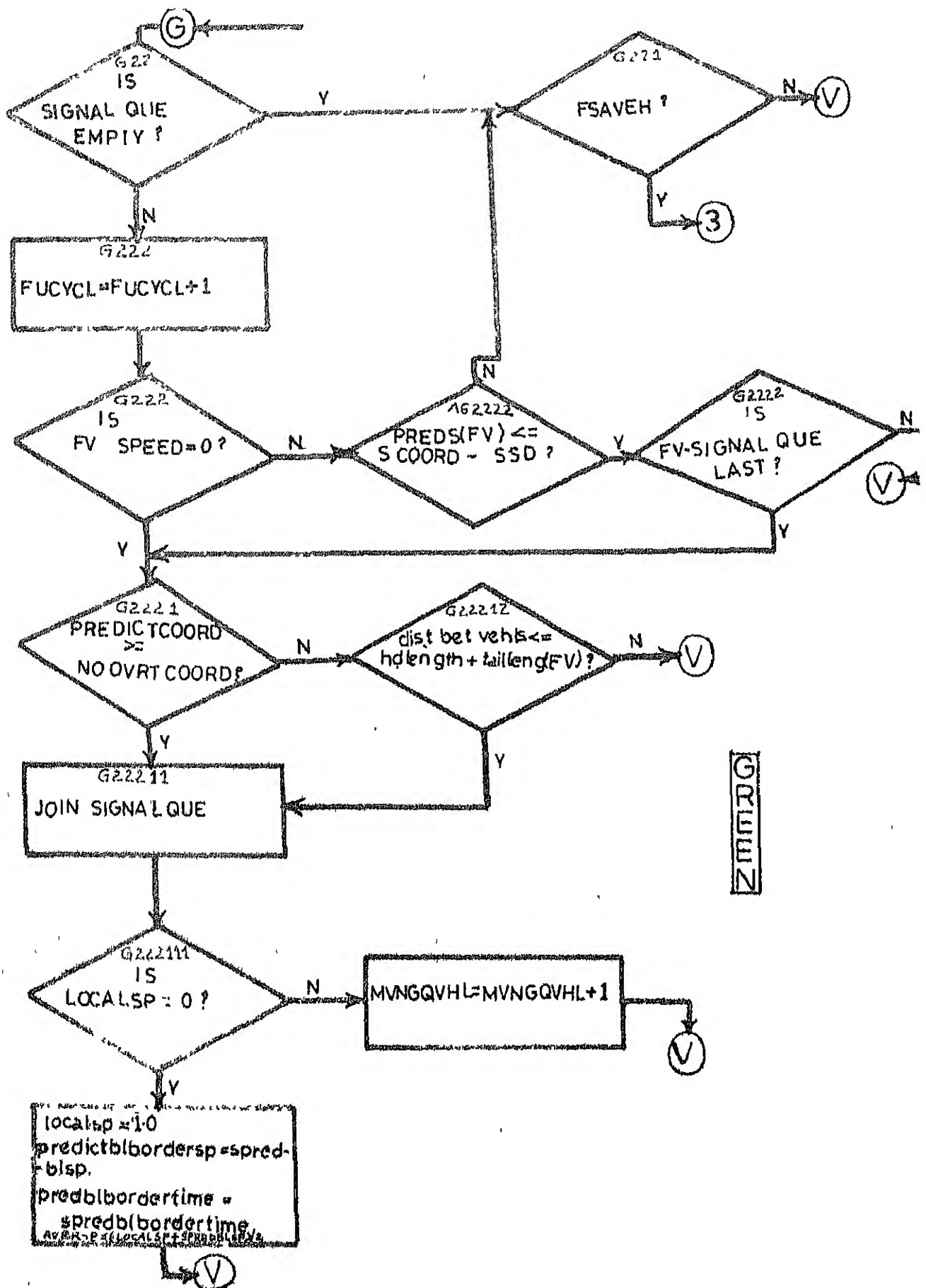
Routine in conjunction with overtaking an equipage

TIMETORETURN. Calculates the time to a possible point for return-
POINT(C) ing from track 3 to track 1. C indicates whether
 the current equipage is free or constrained.

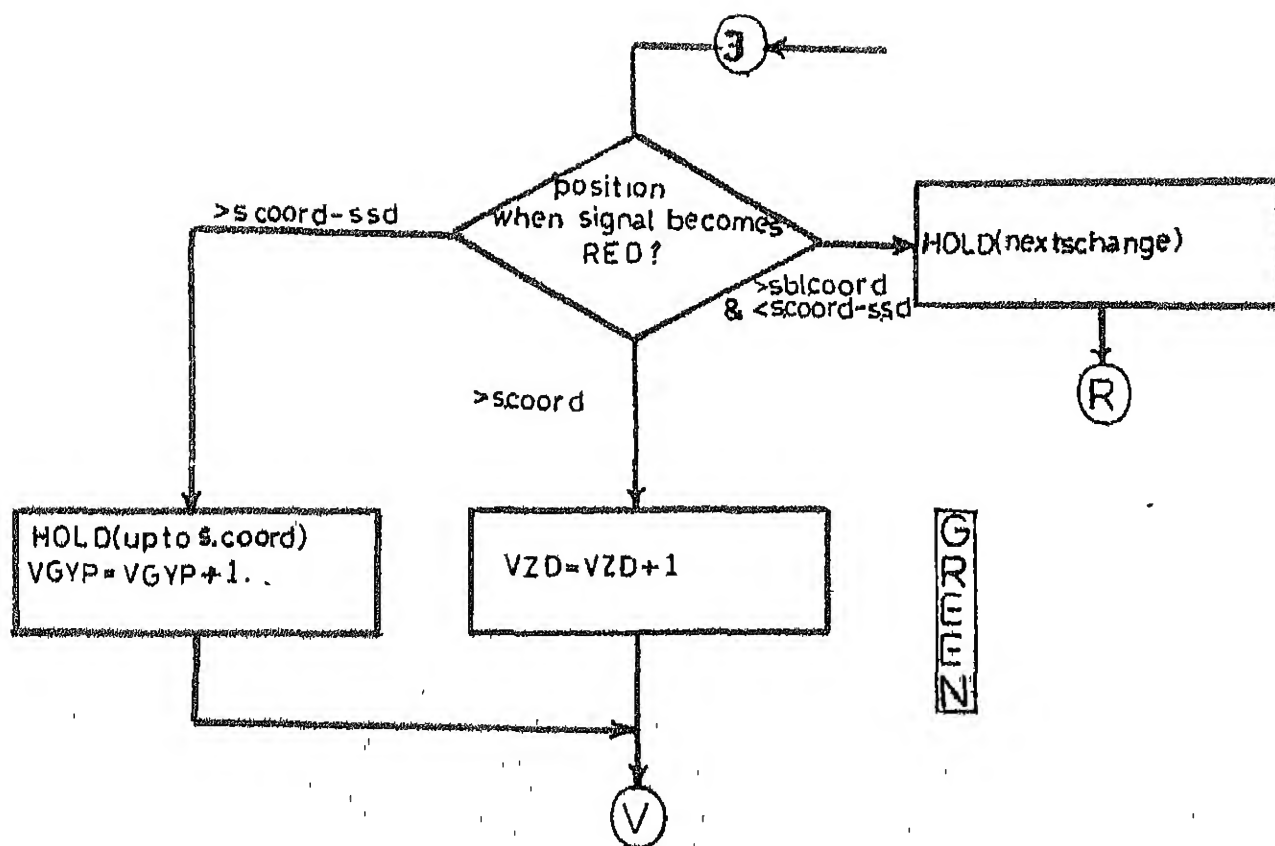
APPENDIX - B
FLOW CHART OF PRESENT WORK

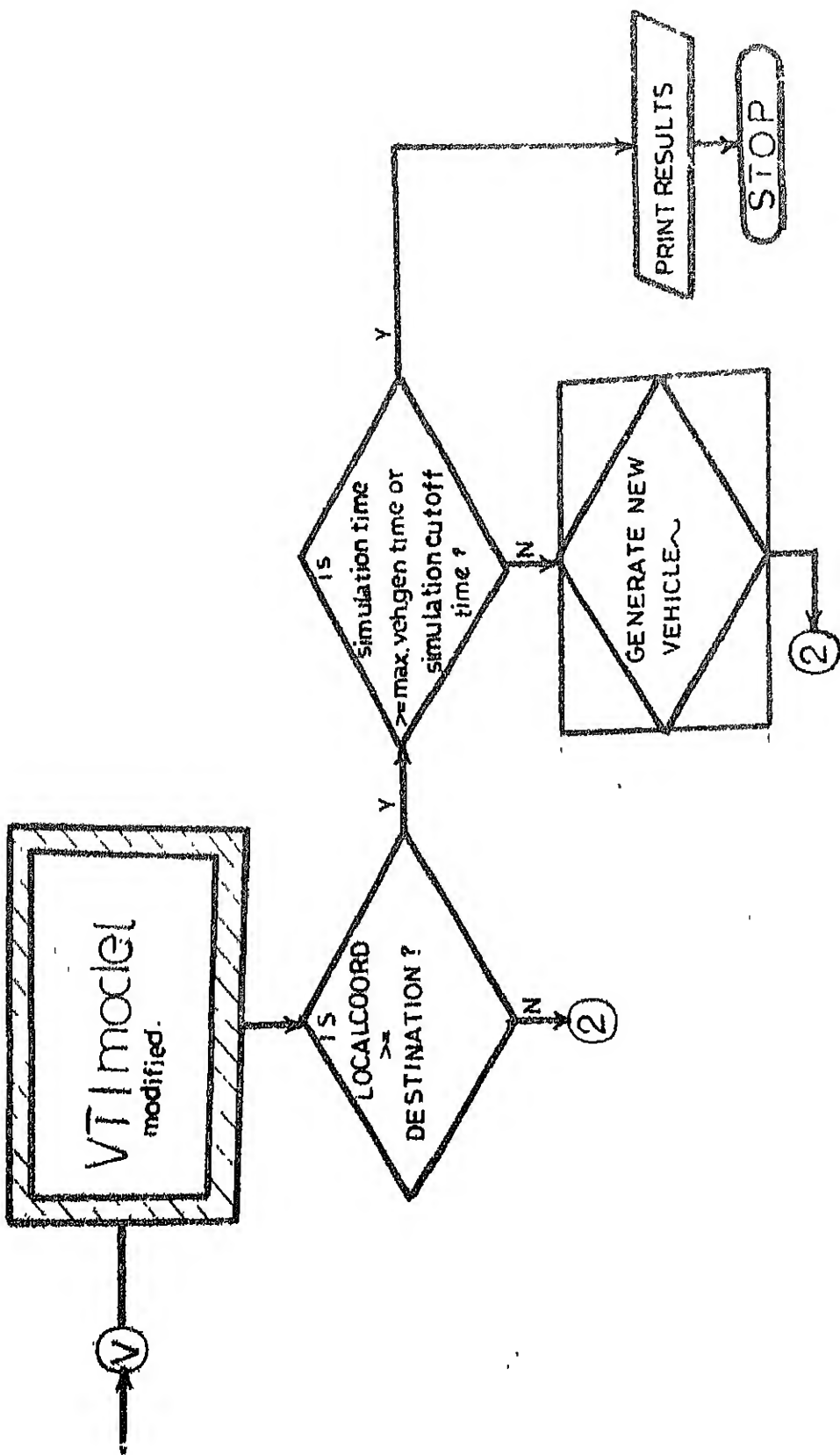






G222.111





FLOWCHART FOR PROGRAMME

APPENDIX - C

LIST OF PROCEDURES ADDED, PROCEDURES CHANGED IN ISRTSM

APPENDIX C

+ 1)	INTEGER PROCEDURE	system signal(any time)
+ 2)	INTEGER PROCEDURE	myposin sigq(Vb)
+ 3)	REF(Veh) PROCEDURE	vehbackwirrk(X)
+ 4)	REF(Veh) PROCEDURE	vehequalitrk(X)
+ 5)	REF(Veh) PROCEDURE	vehforwitrk(X)
+ 6)	REF(Veh) PROCEDURE	platoonleader(Vo)
+ 7)	REF(Veh) PROCEDURE	oncomingveh equalorbackwitrk
+ 8)	REF(Veh) PROCEDURE	oncomingvehforwitrk(X)
+ 9)	REF(Veh) PROCEDURE	lastvehinoncomingplatoon(X)
+10)	PROCEDURE	reactbackw
+11)	PROCEDURE	Reactfor ^W
+12)	REAL PROCEDURE	headleng(b1,b2)
++13)	REAL PROCEDURE	ssd(b)
+14)	BOOLEAN PROCEDURE	behindvehaffected
+15)	BOOLEAN PROCEDURE	beabletfolr
+16)	BOOLEAN PROCEDURE	surprise
+17)	BOOLEAN PROCEDURE	Interesting
+18)	REAL PROCEDURE	oncomvehsightitrk(X)
+19)	PROCEDURE	travel
+20)	PROCEDURE	pts
+21)	PROCEDURE	retard
+22)	PROCEDURE	ts
++23)	REAL PROCEDURE	vspredictnextevtime

+24)	REAL PROCEDURE	predtid
+ 25)	REAL PROCEDURE	tidsrot
+ 26)	PROCEDURE	travelconstrained
+27)	PROCEDURE	travel3
+28)	BOOLEAN PROCEDURE	oncomingvehvisible
+29)	BOOLEAN PROCEDURE	rendezvosormaxsight
+30)	BOOLEAN PROCEDURE	drive(c)
+ 31)	BOOLEAN PROCEDURE	scathingup1
+32)	PROCEDURE	ifextralanebeginreactforw
+ 33)	BOOLEAN PROCEDURE	wanttohelpvehbackwtopas
+ 34)	BOOLEAN PROCEDURE	accouvertakingaccepted
+ 35)	REAL PROCEDURE	ovtaklength(c,vs)
+ 36)	BOOLEAN PROCEDURE	want(c)
+ 37)	BOOLEAN PROCEDURE	catchingupbefpredictnextevtime(vb)
+38)	REAL PROCEDURE TIME	toeturnpoint
+39)	REAL PROCEDURE	timetocatchingupoint
+40)	REAL PROCEDURE	timetostartposibility
+41)	REAL PROCEDURE	timetomasight
+42)	REAL PROCEDURE	timetorendezvousormaxsight
+43)	REAL PROCEDURE	timetoinitialpoints
+44)	REAL PROCEDURE	timetofollow
+45)	REAL PROCEDURE	timetoblocklimit
+46)	PROCEDURE	write(tex)
+47)	PROCEDURE	wrpost(x)
+48)	PROCEDURE	wrivehdata
+49)	REAL PROCEDURE	saccoln

++50)	REAL PROCEDURE	spredictblbordersp
+151)	REAL PROCEDURE	spredblbordertime
+52)	BOOLEAN PROCEDURE	fsaveh
++53)	BOOLEAN PROCEDURE	posfrontveh
++54)	REF(Veh) PROCEDURE	frontveh
+55)	PROCEDURE ACTION SIGNAL	
++56)	PROCEDURE	red
+157)	PROCEDURE	green

1 Indicates changed procedure

+1 Indicates new procedure introduced.

APPENDIX - D
EVENTFILE DETAILS

APPENDIX D

<u>EVENT NUMBER</u>	<u>TYPE</u>	<u>DESCRIPTION</u>	<u>WIDTH</u>	<u>STARTING COLUMN</u>
0	I	Event Type	2	
	T	Title	118	
1)	<u>EQUIPAGE ENTERS A STRETCH OF A ROAD</u>			
1	I	Eventtype	2	1
	I	IDNU	5	3
	I	DIRNU	3	8
	I	ORIGIN	6	11
	I	LOCALCOORD	6	17
	I	DEST	6	23
	I	VEHICLETYPE	3	29
	R	BDS(VON)	6	32
	R	P(P/W)	6	38
	R	TIME+TIMESHIFT (ARRIVAL TIME)	10	44
	R	LOCALSP	8	54
2)	<u>EQUIPAGE LEAVES A STRETCH OF A ROAD</u>			
2	I	Eventtype		
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	I	OWNTRACK	3	33
	R	TIME+TIMESHIFT (DEPARTURE)	8	36

3) PASSING MEASURING POINT

3	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33
	T OR I	Front Vehicle Identification	7	36
	I	VF IDNU	5	43
	I	VB IDNU	5	48
	R	Energy Consumption	7	53

4) DIRECT OVERTAKING STRTED

4	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	P	AVERSP	8	15
	R	LOCALTIME	10	23
	T	OWNTRACK	3	33
	I	TYPE	3	36
	I	VF.IDNU	5	39
	I	VF.TYPE	3	44
	R	VF.AVERSP	8	47
	R	SIGHTLENGTH	7	55
	R	ONCOMVEHSIGHT- ITRK	7	62
	R	ONCOMVEHFORWI- TRK	8	69
	T		4	73

7) PASSAGE POINT

7	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33
	I	TYPE	3	36
	I	VF.IDNU	5	39
	I	VF.TYPE	3	44
	I	VF.AVERS	8	47

8) PASSAGE COMPLETED

8	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33

9) TRACK CHANGE

9	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME + TIMESHIFT	10	23
	I	OWNTRACK	3	33
	I	NEWTRACKNO	3	36

10) FOLLOWING STARTED

10	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33

11) OPPORTUNITY TO DIRECT OVERTAKING NOT ACCEPTED

11	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33
	I	TYPE	3	36
	I	VF.IDNU	5	39
	I	VF.AVERSP	8	47
	I	SIGHTLENGTH	7	55
	R	Distance to Oncoming Vehicle intrack2	7	62
	R	ONCOMINGVEH. AVERSP	8	69
	T		4	

12) OPPORTUNITY TO ACCELERATED OVERTAKING NOT ACCEPTED

12	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33
	I	TYPE	3	36
	I	VF.INDU	5	39
	I	VF.TYPE	3	44
	R	VF.AVERSP	8	47
	R	SIGHT	7	55
	R	Distance to oncoming vehicle	7	62
	R	Oncomingveh.aversp	8	69
	T		4	

13) BLOCKBORDER PASSAGE

13	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33
	R	BDS(VON)	6	36
	I	VEHTYPE	2	42
	R	P(P/W)	6	44
	R	Energy Consumption(W)	7	70

14) EVERY CHANGE

14	I	Eventtype	2	1
	I	IDNU	5	3
	T OR I	VF.INDU	5	8
	I	OWNTRACK	2	13
	T	F if following	2	15
	T	B if behind catching	1	17
	R	LOCALCOORD	6	18
	R	LOCALSP	6	24
	R	AVERSP	6	30
	R	PREDBLBORDERSP	6	36
	R	LOCALTIME	8	42
	R	PREDICTNEXTEVTIME	8	50
	R	PREDBLBORDERTIME	8	66
	T		1	74
	T	TEXT	19	75
	R	LOCALCOORD	6	94
	R	LOCALSP	6	100
	R	AVERSP	6	106
	R	PRE	6	112
	R	PREDBLBORDERTIME	7	118

15) OVERTAKING INTRUPPTED BEFORE LEVEL POINT

15	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33

16) OVERTAKING FINISHED AFTER LEVEL POINT

16	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33

17) FOLLOWING TERMINATED

17	I	Eventtype	2	1
	I	IDNU	5	3
	R	LOCALCOORD	7	8
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33

18) OVERTAKING LEVEL POINT

18	I	Eventtype	2	1
	I	IDNU	2	1
	I	LOCALCOORD	5	3
	R	AVERSP	8	15
	R	LOCALTIME	10	23
	I	OWNTRACK	3	33
	I	TYPE	2	36
	T or I	VB.IDNU	5	38

R	VB.AVERSP	8	38
I	PREDS(VB)	7	43
R	VB.AVERSP	8	50
I	VB.TYPE	2	58
I	INCOMINGVEH.I D	5	60
I	PREDSINCOMINGVEH	7	65
R	ONCOMINGVEH.AVERSP	8	72
I	ONCOMINGVEH.TYPE	2	80
I	ONVF.IDNU	5	82
I	PREDS(ONVF)	7	87
R	ONVF.AVERSP	8	94
I	ONVF.TYPE	2	102

A 91831

CE-1985-M-PRY-TMP

CE-1985-M-PRY-TMP